

An exploration of pre and post-stressed timber forms utilising plantation-grown eucalypt timber

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Signed statement of originality

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Abstract

An exploration of pre and post-stressed timber forms utilising plantation-grown eucalypt timber

This investigation concerns the behaviour of plantation-grown and natural forest eucalypt timber during secondary processing, from sawn and dried boards through to the production of fine furniture.

Tasmanian eucalypt plantations comprise only two species, *Eucalyptus globulus* (*E. globulus*) and *E. nitens*. Most Tasmanian plantations have been managed on short rotations to supply the pulpwood market. However a proportion of Tasmanian plantations have been pruned and thinned and are being grown on longer rotations to produce high quality sawlogs. The specific focus of this research is the timber produced from these sawlog plantations.

Preparatory to the testing phase, a review of previous research on growing and primary processing of plantation-grown eucalypt timber was undertaken in order to better understand how it might differ from native forest timber. It was evident that advances in growing, sawing and drying techniques developed in recent decades have improved primary processing outcomes.

For this study, sawn timber from a commercial sawing and drying trial on 22.5 year-old plantation sawlogs of *E. globulus* and *E. nitens* was obtained. Sawn timber from regrowth-age logs of the most widely available native forest species, *Eucalyptus obliqua*, provided a control for comparison.

The same sawmill produced all of the sawn and dried boards used in this investigation. This removed, as far as was possible, differences in primary processing as a confounding factor in the comparisons.

Research was conducted into secondary processing of the three types of timber. Wood is a complex material with a range of variable micro and macro-scale properties that affect processing outcomes, so this called for craft expertise to be applied. Each stage of processing was fully documented to enable evaluation of the suitability of these timbers for high-end, value-added manufacturing. Packs of timber for study were chosen to give representative samples of the sawn timber produced by the mill. Boards from the packs were randomly selected for evaluation so that the conclusions drawn would be representative of the sets of material under study.

This research encompassed a wide range of techniques required for flat panel construction and the production of more advanced steam bent and laminated forms. A number of modifications to existing techniques and innovative processes, particularly around steam bending, were introduced.

Findings by species:

- Plantation *E. globulus* demonstrated that it possessed exemplary working properties enabling it to be integrated into any form of high-end manufacture. The mid-range density of the material coupled with its strength enables it to be used in high stress applications.
- Plantation *E.nitens* proved to be better than expected in its qualities. The lighter weight coupled with excellent strength leads

to a robust material suitable for many high-end applications where these traits are particularly well suited.

- *E. obliqua*, performed as would be expected of a typical native forest eucalypt. The *E. obliqua* reacted to all of the process carried out in this project within normal furniture maker's parameters for an available eucalypt.

Applying the methodologies detailed in the study, sawn timber from *E. nitens* and *E. globulus* plantation sawlogs was found to be ideally suited to the manufacture of fine furniture. The testing program revealed that for the manufacturing of fine furniture, plantation-grown timber of both species was superior to regrowth-age native-forest *E. obliqua*.

These conclusions are confirmed by a display of the step-by-step photo documentation, material samples from the full range of tests, processes and innovations, and the items of furniture produced in sets of three to demonstrate the practical outcomes for each species.

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Chapter 1: Context for research

Methodology: Introduction

The primary question raised in this project is – can plantation-grown *Eucalyptus globulus* and *E. nitens*, the two eucalypt species grown in Tasmanian plantations, be used to produce high grade furniture? This project aims to address the following specific gaps in current knowledge:

- The lack of knowledge about downstream processing of wood from plantation-grown *E. globulus* and *E. nitens* and how their wood properties may affect practical applications.
- The minimal information available to manufacturers of high-end timber products on the practical and physical comparisons between available stocks of re-growth native-forest eucalypt (commonly retailed as Tasmanian Oak) and the plantation eucalypt timber.
- To date there are minimal practical demonstrations of *E. globulus* and *E. nitens* proving their suitability for fine-furniture making. This research project intends to demonstrate by documenting tests on machining, gluing, laminating, steam bending, sanding and finishing, and finally producing furniture items to support these findings.

Previously I undertook a Masters by Coursework that identified some of the research questions being addressed within this project. The Masters explored seating forms, and as part of that the use of generic eucalypt as



Image 1: MFAD submission 2009

the material (see Images 1 and 2). The mix of species used in that project resulted in the emergence of a number of issues, particularly in colour matching. The variation of the oxidation¹ rates of different species meant that boards that were matched at one stage of production diverged in colour years later. This has always been an issue when using mill run Tasmanian Oak as the individual species sold under this trade name (*E. obliqua*, *E. delegatensis* and *E. regnans*) age differently.

This led me to consider investigating the material qualities of plantation grown eucalypts and their suitability for high-end furniture manufacture and the present research project has been the result.

¹ Oxidation is the process of timber discolouring due to either exposure to air or sunlight



Image 2: MFAD submission 2009

The transition of timber supply from old growth natural forest to managed plantations has been a slow and painful process for many sections of the timber industry.

This project aims to advance beyond the existing material knowledge to demonstrate the potential that these plantation timbers offer. As the research developed a further set of issues were identified and integrated into the overall project, this raised additional questions such as:

- Can these plantation eucalypts be formed into flowing shapes utilizing steam-bending as produced by manufacturers such as Thonet?
- Do existing furniture-making techniques need to be altered to cope with the more open wood micro-structure and lower overall density

of the target plantation eucalypts? This point will be discussed later in the material properties sections.

Harwood (2010) and Washusen (2013) cover the differing strategies of plantation silviculture (sawlog and pulpwood silviculture) and the impact this has on the timber produced. These articles also lay out the progress that has been made to date in the primary processing of plantation eucalypt.

As a major part of the preparatory work within this project, it was necessary to review the complex and wide ranging research that has been carried out into the growing and primary processing of this timber. This was done to better understand the differing qualities of the timber produced from these species when they are grown in plantations.

This research builds on the work done on the silviculture and drying of plantation eucalypts by CSIRO, University of Tasmania and the Cooperative Research Centre (CRC) for Forestry as discussed in Blakemore et al. (2010), Harwood (2010), Nolan et al. (2005), and Washusen (2013). The research conducted by the CSIRO and the CRC for Forestry into the processing of the plantation eucalypts has challenged some of the negative perceptions of these timbers.

Widely published reports such as De Fégely (2004a, p. 19) drew negative conclusions based on back-sawing small diameter logs, a form of processing not readily applicable to eucalypts. These findings have been addressed and contextualised in a number of later reports such as Pearn et al. (2013), Washusen (2013).

However the selective interpretation of many of these early reports by various sections of the timber industry has fostered the belief that these

plantation timbers would always be substandard, and this has led to a reluctance to pursue research into downstream processing² of these materials.

Eucalyptus globulus: Southern Blue gum (plantation-grown). Old growth *E. globulus* from native forests was not favoured by saw-millers or furniture manufacturers as it was dense and difficult to work with. Its strength and durability led to its traditional use in bridge and boat construction. The air dry density of old-growth *E. globulus* is about 900 kg/m³ (Bootle 2010, p. 278).

Eucalyptus nitens: Shining Gum (plantation-grown) is a species native to Victoria and New South Wales. From the information that is available old-growth native forest timber of *E. nitens* has an air dry density of 700kg/m³. (Bootle 2010, p. 283). The research project also used a control native-forest eucalypt species that already has a proven record within the furniture industry.

The control chosen was regrowth native forest *E. obliqua*: Stringybark. Sawn timber from this species is marketed as Tasmanian Oak. Regrowth logs (i.e. logs less than 110 years old, in regrowing as opposed to old-growth forests) represent the most widely available eucalypt timber still available from Tasmania native forests as old-growth availability declines. This project is also isolating re-growth eucalypt specifically, and applying it into high-end applications.

This regrowth *E. obliqua* timber has been in use for many years but mixed in with old-growth timbers, so not enabling specific conclusions to be drawn on its properties.

² Downstream processing refers to the secondary processing of timber into items such as furniture and other items.

This species (*E. obliqua*) has well-known working properties and it is accepted as a standard material in furniture-making and thus provides a relevant comparison to the plantation-grown timbers. The air dry density of old-growth *E. obliqua* is around 780 kg/m³ (Bootle 2010, p. 310).

Other available native-forest species such as *E. regnans* and *E. delegatensis* were considered however as they are prone to a much wider range of variation in appearance and density this made them less suitable as control samples, although together with *E. obliqua* their timber is marketed under the same trade name of Tasmanian Oak.

From a furniture maker's standpoint the visual appearance of the material is important, so the more uniform colouration of the *E. obliqua* was an important factor in its selection. Species such as *E. regnans* can be quite variable in colour, making them more difficult to match across table tops and other widening joints.

The harvest age in regrowth native forests is based on the dimension of the tree, not necessarily on its age, but regrowth forests are generally considered to be less than 110 years old, having regenerated after historically dated wildfire or logging, whereas old-growth eucalypt timber, traditionally used in furniture-making but now declining in availability, is older than this (Forestry Tasmania 2014).

Since the early 1970s there have been many milling and processing trials done on plantation *E. nitens* with varying degrees of success.

A commercial scantling product cut from 10-15-year-old small-diameter plantation trees grown on pulpwood rotations (with no thinning or pruning) was marketed as Eco Ash by FEA (Forest Enterprises Australia). From personal experience this material was full of knots and unsuitable for high-end furniture manufacture. Large numbers of knots

can be problematic as they affect the structural integrity of boards. In applications such as furniture-making the cross sections of timber used are smaller than architectural or building applications, however they need to maintain strength. Some species such as *E. nitens* that have bark inclusions around knots causing weakness in the sections of boards where they are present.

If the correct plantation management, in particular pruning and thinning, to yield larger-diameter clearwood logs and appropriate sawing and drying procedures, as described by Washusen (2013) are followed, then the resulting timber demonstrates potential for exploring high-value secondary processing. Specific silvicultural regimes (pruning and thinning) have been developed for a small fraction of plantations intended to produce sawlogs rather than just pulpwood.

One of the points of interest of this project is to highlight the benefit that pruning and thinning of plantations may offer by demonstrating the potential uses of pruned plantation sawlogs. Currently there is no major incentive to prune these plantation trees in their early stages of growth due to a number of external factors. A major one is the loss of government financial support for the pruning and thinning of plantations.

This project aims to highlight the potential of the clear wood produced by this strategy. The costs of pruning and thinning, which are at least \$1000 per hectare, according to Harwood (2010, p. 2), will have to be recovered through higher log prices if growing plantation sawlogs is to be a financially viable long term enterprise. Timber demand from high-end users is required for sustainable plantation sawlog production.

This research project explores the potential for high-value furniture-making using plantation grown eucalypt sawlogs, and provides

documented and practical demonstrations of this potential. The following literature review explores the current and past research carried out on the plantation eucalypts.

From a furniture maker's perspective, it is necessary to know what has been done to produce a material to fully understand how and why it reacts to certain downstream processes.

Differing milling and drying techniques can have a major impact on the timber produced, and so it was necessary to determine how current processes have evolved and the impacts that this evolution have had on the quality of the timber produced.

Literature review

This literature review considers relevant articles and reports exploring aspects from silviculture through to the supply and downstream processing of the plantation timber.

A brief history of plantation eucalypts of Tasmania

Plantation eucalypt management in Tasmania has evolved from the first experimental plantings in the 1970s. After testing many species, those finally selected were *E. globulus* for low elevations and *E. nitens* for high-altitude plantings as the latter is more frost resistant than *E. globulus*.

Tibbits (1986) discusses the planting rates in the early 1970s of 20 hectares per year. This greatly increased in the 1990s and 2000s, leading to a total area of approximately 230,000 ha of plantation eucalypt in 2012 (Forest Practices Authority 2012, p. 7).

Harwood (2010) states that as of 2010 over 80% of the Tasmanian plantation stocks have been grown on a pulpwood regime making the timber of minimal use as a furniture timber.

The majority of these plantations have been grown to supply the pulpwood market. The timber produced in these plantations contains a large percentage of internal knots making them less suitable for high-end applications.

There has been a small percentage of this total area managed by pruning and thinning with the aim of producing high value sawlogs, such as the logs that supplied the timber used in this project.

There has been continuous debate about the utility of these plantation timbers for uses other than pulpwood from the 1970s. The constant comparison between native forest and plantation timbers and their respective value, flagged in talks such as *Comparing old-growth, regrowth and plantation timber* Volker (2004) suggested the need for more research to be done on the integration of the plantation species into general production.

Further work on the plantation eucalypts completed by Washusen et al. (2004) started looking at the application of these plantation materials into higher end products.

Available supply of plantation sawlogs in Tasmania

The projected available volumes are significant, with the latest published supply estimates of 70,000 cubic metres of *E. nitens* and 30,000 cubic metres of *E. globulus* per year of high grade logs by 2027-2028. (Forestry Tasmania 2014).

This volume of sawlogs if processed into board form this would secure an ongoing resource for high-end users. This is projected through to 2098 (Forestry Tasmania 2014, p. 19). The annual harvest of plantation logs augments the current log harvests from native forest (old growth and re-growth) timbers.

The volumes of plantation sawlogs from the first thinned and pruned plantations are now available in sufficient quantities to draw substantive conclusions as to their viability as furniture timbers.

A much smaller area of plantations have been pruned and thinned and available for harvest. In 2010 projections were that approximately 40,000 ha of Tasmanian plantations would be pruned and thinned.

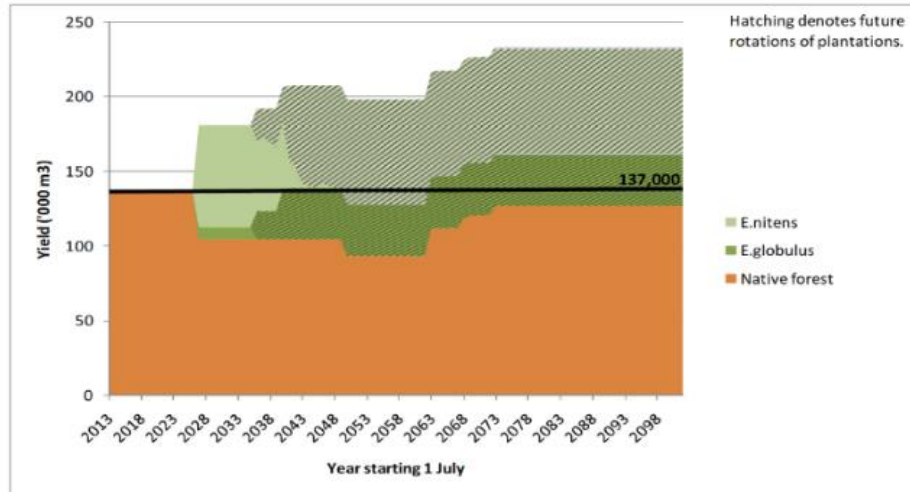


Chart 1 Forestry Tasmania High quality sawlog sustainable yield review No. 4 (Forestry Tasmania 2014, p. 19, Fig 8)

Harwood (2010) states that pruning reduces the occurrence of internal knots and thinned to yields larger-diameter logs suited to quarter-sawing, increasing their viability for furniture and other higher end production.

This area of thinned and pruned plantations is now known to be an over-estimate. Some scheduled pruning and thinning has not occurred, because of the downturn in the forestry industry and a reduction in available funding for these operations.

Projected sawlog supplies from plantations of *E. nitens* (light green) and *E. globulus* (dark green) are shown in Chart 1; by the late 2020s they are projected to exceed 105,000 cubic metres per year.

This available resource represents a significant opportunity to expand the uses of plantation sawlogs into the future as reported by Forestry Tasmania (2014), and Washusen (2013). Having said this, my research

project specifically explores plantation timber as a possible alternative to stocks of native forest timbers for high end applications.

The Britton Brothers milling trial reported by Pearn et al. (2013) yielded sufficient quantities of high grade, large section sawn timber allowing this research project to proceed. As this was a commercial sawing and drying trial, the resulting timber can be compared directly to the output of a commercial mill using existing technology and current best practice in sawing, drying and reconditioning. This is a critical point as the proof that existing infrastructure can be used to produce high-grade timber from plantation logs demonstrates that integration of this material into existing mills is possible.

After the commercial trial reported by Pearn et al. (2013), which saw 98% Standard And Better (SAB) grades in 38 mm *E. globulus* boards being returned, there can be no question that this plantation material has potential.

Articles such as *The nature of reaction wood. -5. The distribution and formation of tension wood in some species of Eucalyptus* by Wardrop (1956) was of interest in this project as smaller diameter eucalypt logs have been noted to display greater occurrences of this defect.

Factors such as proximity to other trees can cause the development of bands of tension wood, which can reduce recovery of sawn boards and also cause subsequent problems in drying of boards through excessive non-recoverable shrinkage. *Eucalyptus globulus* is particularly prone to the occurrence of tension wood according to Washusen (2013).

Other reports such as De Fégely (2004a) identify the growth stresses in the tree stem that affect eucalypts generally.

When the timber is affected by the internal stresses it can create significant difficulties in techniques such as cabinetry, associated with tension wood where re-sawing timber occurs, as this releases the inbuilt tensions in the timber causing it to spring, bow and warp. This is discussed by Hoadley (2000), and Lloyd (1966, p. 55). This results in major loss of dimension in milled boards as they have to be straightened. This has been flagged in industry reviews such as De Fégely (2004a). The critical point is that on the silvicultural side, once tension wood is formed, it cannot be removed and must be managed within downstream processing. Some advances in processing to minimise its effects are noted by Washusen (2013, p. 49).

Rozas et al (2000) discusses the possibilities for *E. nitens* to be used in furniture production. As this paper was relatively early in the chain of research with the plantation timbers they were reporting on trees harvested in Chile at 15 years of age. They reported that this material suffered from major cellular collapse during processing. The collapse and associated distortion was mostly due to the small diameter logs used in this project. The small diameter logs necessitated a milling strategy yielding mostly back-sawn boards and this, in many eucalypts, causes drying defects to be amplified.

The use of differing milling techniques in the primary processing has improved the resulting material to a point where it is viable as a furniture timber. Steele et al (1993) reported on the volume return between the different sawing strategies this and this led to a change from back-sawing to quarter-sawing. This has produced stable materials for the end user.

The major differences between these sawing techniques as they apply to this project will be discussed in Chapter 2. The report by Washusen et

al. (2004) also identified that the quarter-sawing method of milling recovered a larger proportion of select timber than the back-sawing methods previously used on smaller logs.

This study compared pruned stands of *E. globulus* from Busselton in south Western Australia (21-22 year old) and unpruned stands of *E. globulus* from Traralgon in Central Gippsland (32 year old). This research concluded that there was a much higher percentage of C-grade or better logs produced in comparison to the unpruned logs. They also concluded that the unpruned logs delivered 10% less sawn timber from equivalent graded logs.

Later research confirms that larger diameter logs that allow different milling strategies provide higher quality outputs. This is covered by Pearn et al. (2013), Washusen et al (2007).

Washusen (2009), Washusen et al (2007) identified the higher yield of material using back-sawing in comparison to quarter-sawing. However the drying degradation from surface checking in the back-sawn timber caused a much higher rate of standard or lower grade material to be produced.

The major review carried out by Nolan et al. (2005) for the Forest & Wood Products Research and Development Corporation is a comprehensive report on the status of the plantation hardwood resource at that time and explores the factors affecting its future sustainability in very considerable detail.

Published a decade ago the review retains its importance because of the emphasis it places on the application of appropriate silviculture

techniques throughout the life cycle of Australian hardwood plantations until they are harvested.

The authors demonstrate how essential it is to ensure that pruning of plantation trees occurs during the early stages of growth if they are to produce high value sawn timber. This produces a far higher quality of product, important for sawn logs for the high end timber and furniture industries, since failing to prune early in species such as *E. nitens* and *E. globulus* lead to significant defects in the timber once sawn.

If limbs are left on the tree, the knots that occur in the sawn product form structural defects that can downgrade the timber and render it unusable for higher end applications.

It is also important to note that the emphasis on early and regular pruning leads to a further significant benefit, it produces figuring that is prized in furniture for its decorative qualities.



Image 3

Splay knots in *E. nitens* with encased bark causing the knots to be unstable



Image 4

This figuring is caused by wood laid over the pruned branches

Sawing and drying plantation grown E. nitens and E. globulus by Pearn et al. (2013) is a pivotal report for this project as it describes the production of the plantation materials used. This trial used existing equipment and techniques proving that processing plantation materials can be commercially viable without the need to invest in specialized plant or equipment.

The trial was able to produce larger section 150 x 38 *E. nitens* with minimal internal collapse.

This trial employed drying and reconditioning schedules developed in previous research on drying plantation-grown *E. nitens* by Blakemore et al. (2010) and has led to improvements in the quality of the resulting timber.

Biechele et al (2009) discuss the research being done in Chile and how this may be influential in the local context. The longer rotation of their plantations is of particular note as the bigger trees are less problematic to mill and dry generally producing higher grade materials.

The report *Processing methods for production of solid wood products from plantation-grown Eucalyptus species of importance to Australia* by Washusen (2013) is a synthesis of all the solid wood production research that has been done to date. The only point that I have issue with is the recommendation that back-sawing be pursued in *E. globulus* and *E. nitens*. Even with the correct drying and management of the product through processing the outcome will be problematic for high end users. The ongoing instability of back-sawn eucalypts does not end at the mill gate, it is carried through to the end product.

From my past experience with this material it has to be treated with special care. For instance you would not use a back-sawn eucalypt board in a table top as it will cup over time. This makes it difficult to convince furniture makers to use this material as the long-term risks to their reputation are not worth it.

The issue is that the cyclic expansion and contraction associated with changes in moisture content of sawn boards, is much greater in the radial than the tangential direction. As the back-sawn boards have the radial dimension running across the width of the board this magnifies the movement effects resulting in the board cupping.

There are ways to overcome this but they are costly and time consuming to undertake, and result in minimal visual benefit relative to quarter sawn boards.

Milling and drying

The drying and processing methods are a critical element of the preparation of timber used in high-grade applications. If the materials have not been prepared correctly faults carry through to the end product. These can vary from minor checking through to major structural defects that render a material un-usable for furniture. This realization led to the exploration of other articles delving into the primary processing of the plantation eucalypts used in this project.

Furniture from young plantation grown eucalypts by Ashley et al (2000) was very early in the chain of research into plantation eucalypt and its application for high end uses.

At that time the milling and drying process had not been refined, leaving many questions relating to the suitability of the materials for high end uses. These issues were later addressed in such projects as Innes et al (2008) and Washusen (2011). These later research projects refined the processing and addressed the majority of the issues that the early research identified.

McKenzie et al. (2003) concluded that with the correct drying techniques applied the internal checking on *E. nitens* boards was reduced. This report also was able to draw parallels however, in results with the *E. nitens* trials being carried out in Chile. As the trees in this research project were 17 years old, this fits with subsequent findings that the larger

diameter (older) logs return on average higher grade larger section material that are less prone to destructive drying issues.

This report *Solid wood quality and processing performance using conventional processing strategies* by Washusen et al (2007) was of relevance to this project as it looked at the recovery of quarter versus back-sawn boards.

The recovery of the back-sawn select boards was higher in the initial stages, however due to surface checking this decreased the return of standard and select boards.

The quarter sawn boards returned a higher value yield overall. This reinforces the quarter-sawing method as the preferred option for high end applications. Further research confirmed that the lower overall recovery was more than compensated by higher grade recoveries.

The report *Plantation-grown Eucalyptus nitens: solid wood quality and processing performance on linear sawing systems with a range of commercial and experimental drying schedules*, undertaken by Blakemore et al (2010) made use of methods developed in previous research on drying plantation eucalypt, with the drying and reconditioning schedules developed in this study leading to improvements in the quality of the resulting timber.

Articles such as *Growth strain in Eucalyptus nitens at different stages of development* by Biechele et al (2009) discuss the research being done in Chile and how this may be beneficial in the local context. The longer rotation of their plantations is of particular note, as the bigger trees are less problematic to mill and dry generally producing higher grade

materials. This has been a recurring finding in most recent reports relating to the milling and drying of plantation eucalypts.

Surface discolouration

Some discolouration of the surface of the *E. nitens* received from Brittons was evident. This led to some research into the possible causes of this phenomenon. The colouration of the surface did not appear to be a major issue as there was no structural or mechanical downgrading of the material but, none the less, it was necessary to look for a possible cause. Observations of unusual surface markings on the *E. nitens* led to the article by Kibblewhite & Johnson (2001). The elevated levels of Xylose may well explain this colouration as it is contrary to normal staining.

Further downstream applications for plantation eucalypts

It was necessary to explore other applications for the plantation eucalypts as solid wood, there are quite often issues or observations identified.

Reports into the lamination of eucalypts are relevant to this project as it explore other methodologies that may be applicable for this research. They include *A review of the utilisation of hardwoods for LVL*³ by Ozarska (1999) which was of interest as the North American species in normal production have a basic density⁴ of 390-500 kg/m³.

This is a similar range to *E. nitens* so it was interesting to look at their processes to see if any were applicable to this project.

³ LVL refers to Laminated Veneered Lumber a form of reconstructed timber usually used in building applications but has been used in furniture.

⁴ Basic density is usually represented by ADD (Air Dried Density)

One of the ongoing criticisms of the *E. nitens* is its low average air dry density of 560 kg/m³ compared to standard eucalypt species such as *E. obliqua* with an average air-dry density within this testing program of 670 kg/m³. The greater this density the more difficult it becomes to work with the timber. For example, Tasmanian Sassafras (*Atherosperma moschatum*) is excellent to work with and has an average density of 420-630 kg/m³. Ozarska's article discusses the use of lower-density softer timbers in the production of LVL and this may be applicable to the plantation eucalypts.

This report goes hand in hand with the later LVL (Laminated Veneered Lumber) trials from New Zealand undertaken by Gaunt et al (2003). The findings of this report were that the lower density materials were fit for purpose in LVL making the plantation *E. nitens* and *E. globulus* applicable in products such as LVL and ply.

The report *Temperature and moisture content behaviour in microwave heated wood prior to bending—Mountain Ash (Eucalyptus regnans)* published by Studhalter et al (2009) was of some interest as one of the intended outcomes of this project is to bend eucalypts. The project was able to achieve reasonable bends in eucalypt wood in line with the achievable radii using traditional methodologies. Subsequently there was no imperative to explore this technology as microwave heating of the timber is impractical on a small scale; it was, however, of interest to see what degree of bends they were able to achieve with that form of technology. Within this project similar degrees of bending were achieved with modified, traditional steam-bending methods.

The scientific information about the plantation timbers is an important backstop to the later applied use of these timbers. The application of all

of this research has led to timbers that would not exist without the work done on the silviculture and primary processing side.

These timbers have now reached a point where they can be analysed and compared to known timbers gauging their suitability for high-end applications. This leads to the next stage where craft knowledge has to be applied to the plantation eucalypts to evaluate their suitability and if they are indeed useful for furniture making.

This concludes the literature review relating directly to the materials that have been tested and evaluated in this research project. The project did, however, also involve a very extensive reading of craft and design-related articles and monographs. A selection of these have been included in the bibliography where they have directly influenced the development of this research project and a further small selection of these have also been included in an annotated bibliographical section that precedes the list of illustrations on page 170.

Conclusion Silviculture and primary processing

As this project is framed around sawn timber from plantation-grown eucalypts, gaining an intimate understanding of the material is critical. It has been necessary to delve into the back story of previous research to piece together what has brought about these plantation materials.

The perspective of the end user has not been captured to date, as the timber has not been available to analyse and compare with known timber types sourced from native forests.

The greatest difference between these timber sources is the result of the different silviculture (sawlog plantation versus natural forest) with some additional visual and structural variation attributable to the species differences.

Silvicultural research is a long and involved process with speculative experiments done with the results taking 20+ years to reach a stage where the materials are available for further evaluation. As with any crop plantation silviculture, sawing and drying must all be optimised to produce sawn boards suitable for high-value secondary processing.

The introduction of a new timber or material is always met with scepticism and trepidation, particularly if it is unlike anything that has previously been in general use. Adding to this knowledge dispels the misgivings associated with an untried timber.

Chapter 2 : The testing process

Methodology

The primary research questions centre on the suitability of plantation eucalypts for use in fine furniture. This project relies on the plantation timber being able to be manipulated to achieve what plantation eucalypt was not believed to be suitable for. Throughout the process it was necessary to demonstrate the differences between the plantation timber and current supplies of native-forest eucalypts, and to capture any modifications necessary to aid the integration of the plantation species into normal practice.

During the initial testing phase of this project it became evident that the plantation eucalypts offered opportunities for a wider scope of work to be undertaken. As a major part of the process of analysing the plantation materials it was necessary to use a more scientific approach to the testing. Using a control species, *E. obliqua*, meant that a quantifiable control, or standard, was there upon which to base the conclusions.

Throughout the testing phase of this project each process was conducted using the same equipment, materials and processes to gauge the comparative working properties of each species. This approach enabled the direct and substantive comparisons to be drawn between each of the timbers. Having the opportunity to devote time to this is a luxury that is not normally afforded in any commercial fine-furniture-making setting or within the normal making process. Under normal commercial circumstances, some of the processes would have been carried out as a matter of course although they would not usually be recorded.

Consideration was given to processes that would have the best chance of demonstrating any challenges, if they existed. There was no point in

devoting time and materials if there was little or no risk of failure. This approach was based on personal experience gained in a previous coursework master's project, as well as over 38 years working as a fine-furniture maker using Tasmanian species.

Comparative approach to material selection

Throughout the research project it was necessary to maintain a representative selection of the available material rather than to 'cherry - pick' the best of the available timber. As will be shown in the final presentation, the timber has been used 'as is' and the furniture was deliberately allowed to display the typical flaws that might crop up in a pack of milled timber. This approach has enabled the standard grading techniques from the mill to be carried through to the end result.

The selection of the control species used in this trial was from the same supplier to maintain consistency in the milling and drying practices used. The supply of the material from the same mill reduced the potential confounding effects of differences in primary processing, although the native-forest *E. obliqua* was dried and reconditioned using different schedules to that used for the plantation-grown timbers.

From a furniture-maker's viewpoint it is necessary to be able to rely on the initial grading as this is a guarantee that the material meets an expected standard. The mill grading for the *E. globulus* and *E. nitens* was SAB (standard or better) as this was the grading range used by the mill in this trial, while the *E. obliqua* had an equivalent grading. This would be the normal grading range used by high-end users such as fine-furniture makers.

The timber selection process

The packs of *E. nitens* were in a range of thicknesses and widths to best represent a cross-section of the material. It was decided that 100 x 19, 125 x 25, 150 x 25 and 150 x 38mm cross-sections would give the best representation of the available material. The visual inspection of the packs when they were delivered to the Centre for the Arts was important as this was the first time that the material could be assessed. Prior to this, the only indication of the quality of the timber was from the mill's run sheets.

The first look at any material sets the tone for the subsequent processes undertaken. If the timber presents problems, then the majority of time is spent trying to cope with these.

The various packs were viewed and selected in the Brittons Mill, Smithton (Image 5)⁵ then transported to Hobart.

⁵ The pack notation of Tas Oak is because the mill deals with a majority of minor species, represents the abbreviation used for all eucalypts within that particular mill



Image 5: Brittons Mill *E. nitens*

The overall impression of the *E. nitens* was positive, as it proved to be superior to previously available samples of the same species. The timber from these trials had a number of structural issues (Washusen 2008).

In the initial inspection of the packs there was only one board found with any form of major collapse. This was in an outer board not on the mill listing for any of the packs and had been used to protect it from forklift handling damage, this I discounted as a rejected board within the mill's grading.

The variations in figure through the packs is demonstrated in Image 6 which shows some of the figuring present in the *E. nitens*. This was a pleasant surprise as none of the previous trials had demonstrated any major decorative traits.



Image 6: *E. nitens* figuring

The solid figuring in these boards appears to be from small bud traces that have continued to grow and they create an effect that is not dissimilar to that of Birds Eye found in Huon Pine.

This feature I have nicknamed “Quoll”, as it resembles the markings of the local eastern quoll a small carnivorous marsupial (*Dasyurus viverrinus*).

Further to the visual inspection, the recording of the moisture content of the boards as they arrived was critical. The timber was being introduced into a hostile environment as the School of Art’s building is centrally heated and has no humidity control. This causes a major drop in the bond-moisture levels within the boards as the normal Equilibrium Moisture Content within indoor environments in Tasmania (EMC) sits around 12-14% recorded by Bootle (2010), Joyce (1970), Walton (1952). This drops to under 6% over a period of 7 to 10 days when introduced into the School, these readings were taken with a Proto-Meter. This not a normal type of environmental change as the School of Art workshops are a former freezer complex, with floor and wall packing designed to insulate and reduce moisture.

This is an incredibly harsh dry environment for the material to be put through however this afforded the opportunity to study the movement factors of the three species when exposed to stress of this type.

The moisture content on arrival along with the overall dimensions (tangential and radial) were recorded along with the pack number in order to track the expansion and contraction ratios. This moisture content was measured with a Proto-Meter graduated to Douglas fir (*Pseudotsuga taxifolia*) as the normal standard benchmark these machines use.

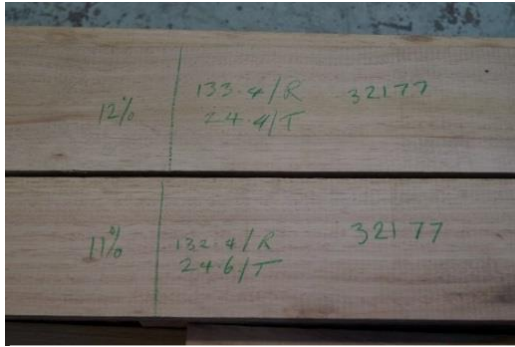


Image 7: *E. nitens* Moisture Content

This is a vital point from a furniture maker's perspective, because if the movement percentage is too great, there have to be accommodations made within the design process to allow for this variation. The shrinkage rate

of all the materials was well within the expected range given that the timber had dropped from between 11-12% (Image 7) to a uniform 6% moisture content according to the Proto-Meter.

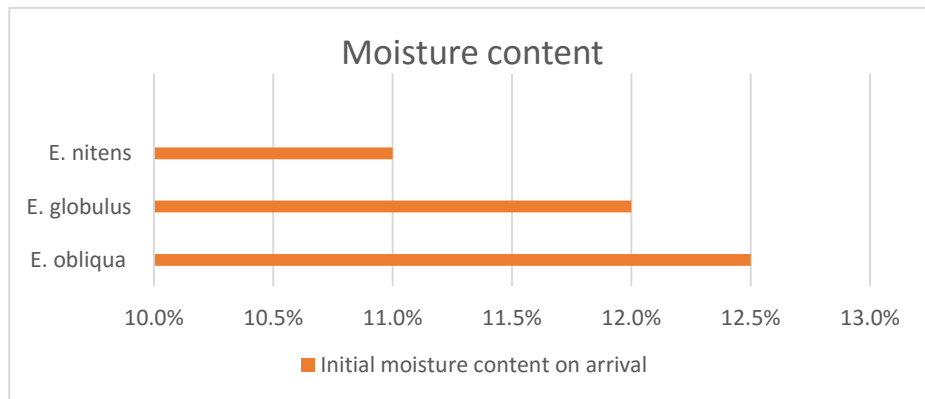


Chart 2

The readings from the meter (Chart 2) gauge do not give a direct measure of moisture content. They rely on the water contained in the sample to conduct electrical current. There are many factors that can cause variation within the readings, the natural resistance of the timber as well as the placement of the probes. Even using this crude measurement system this EMC was extremely low in comparison to normal workshop conditions.



Image 8



Image 9

Subsequent testing was done towards the end of the project to clarify the working moisture content of the timbers during the testing and construction stages. To confirm the moisture contents of all of the timber used in this project ten random samples cut to accurate dimensions (100 x 100 x 33.3mm) in each species and weighed using a set of scales⁶ (Image 9). Each of the 30 random samples (Image 8, 10 samples from

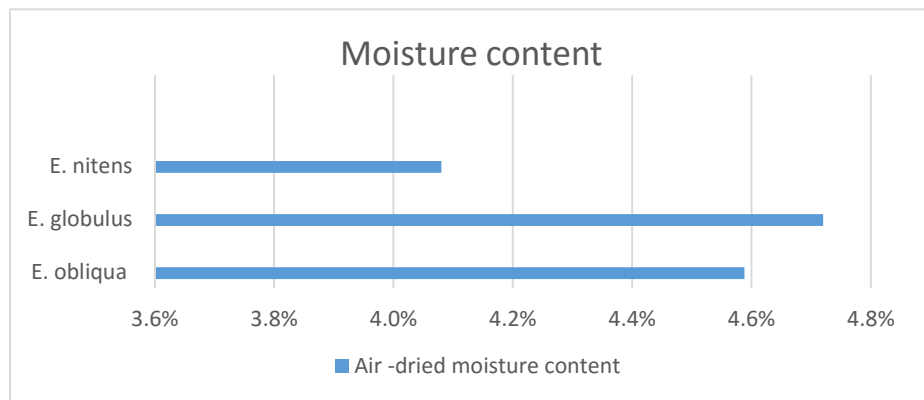


Chart 3

each species) was initially weighed to gauge the air-dry weight then oven-dried for 48 hours at 110 °C to completely dry out any moisture remaining in the samples. The oven-dry weight was subtracted from the air-dried weight figure to obtain the water content of the sample, which was represented as a percentage of oven-dry weight (Chart 3).

The overall results were typical of timber within the school environment. This moisture content is very low, after the timber acclimatised there was

⁶ Set of balance scales capable of weighing 0.01 gram

no major surface checking or other signs of degrade with in any of the plantation species. There were some surface checks that open-up in the *E. obliqua*: these were only minor although this does point to the plantation species being more robust when confronted with such harsh conditions.

Density of timbers used in this project

In addition to the moisture content tests it was also important to capture the density of the materials being compared. The samples prepared to determine the moisture content of the timber were also used to ascertain the average density of each of the test species. This ADD⁷ was estimated by calculating “weight over volume” multiplying each sample out to the m³ then averaging the results. As the density is different to the documented old-growth timber of these species it was necessary to record these to level the playing field.

Old-growth *E. nitens* has an ADD of 700 kg/m³ (Bootle 2010, p. 283) whereas the plantation-grown timber used in this research had a mean ADD of 559 kg/m³. The other species were similar showing a difference between the old-growth and the plantation grown material. Old-growth *E. globulus* has a density of approximately 900 kg/m³ (Bootle 2010, p. 278) as compared to the plantation timber studied here at 584 kg/m³.

The *E. obliqua* varied less, with the old-growth timber having an ADD of 780 kg/m³ (Bootle 2010, p. 310) compared to the regrowth⁸ material

⁷ Air dry weight in kg per cubic metre

⁸ Re-growth refers to native forest regeneration with an age range between 30 and 100 years

under study at 676 kg/m^3 . The regrowth material used as the bench mark throughout this research is representative of the spread of density in normal use in the furniture-making field.

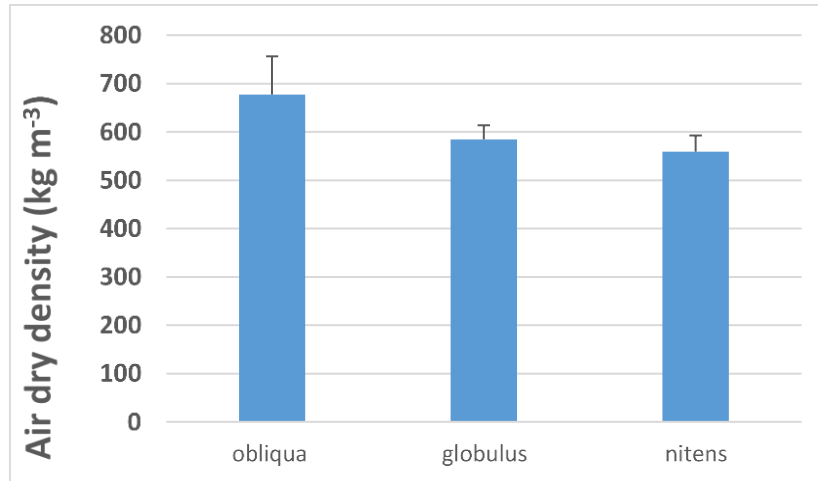


Chart 4: Air dry density of the three species
(error bar shows standard deviation)

Chart 4 represents the comparisons of average density between each of the species being studied. The range for the density of ten individual samples within each species was:

- *E. obliqua* 496.2 kg/m^3 - 713.3 kg/m^3
- *E. globulus* 523.9 kg/m^3 - 616.8 kg/m^3
- *E. nitens* 483.9 kg/m^3 - 593.2 kg/m^3

This fits with the tacit knowledge based appraisal of the species throughout the testing phase of this project.

Initial visual impressions of the samples by species

E. globulus:

Has a uniform grain structure with no problematic variation between the spring and summer wood. This uniformity of grain structure makes it easy to use in most applications. The timber is uniform across all the samples received. The uniformity of grain configuration is a bonus, as it is always difficult to colour match eucalypts with all the variations normally found in the mix of species and age ranges marketed as Tasmanian Oak.

The colour of the *E. globulus* was also worth noting as it was not the usual dark oak colour associated with Blue-gum⁹; this is advantageous. The darker shades of eucalypt are difficult to blend within any larger job as the rest of the piece has to be stained down to the darkest common denominator. This is a problem if a client requires a lighter shade to be maintained throughout the work. There were no major blemishes or knots present in any of the samples that have plagued previous trial samples.

There was a small additional quantity of *E. globulus* (6 boards 125 x 25mm) sourced from Kelly's mill at Dunalley, Tasmania and these were from a private plantation. These boards were only used for some of the finishing tests alongside the timber from Brittons, although they were later rejected as part of the thesis because the provenance of the supply could not be proved.

⁹ The colour and general appearance of *E. globulus* is based on old-growth timber that tends to be far darker than either the plantation or re-growth equivalents

Unfortunately the mill was destroyed in the fires that affected most of Dunalley, which led to the loss of any records pertaining to that timber.

E. nitens:

The overall impression of the *E. nitens* was that the 19mm boards had a higher occurrence of staining issues with more knots present than any other dimension. This, on reflection may be because the 100 x 19mm contained 23% of its volume recovery from logs 300-399mm in diameter. With the remaining being cut from the outer parts of the larger diameter logs. This dimension board represented the highest percentage recovered from the smallest logs documented by Pearn et al. (2013)

The 25mm boards were on average better from a visual and defect perspective as there were fewer knots and almost no surface staining. The quality of these boards was overall better than the 19mm as there was less distortion or piping present.

The 38 mm boards were extremely good with little in the way of defects, and the occurrence of internal pipes was minimal with the overall quality excellent. The 25 mm boards also had minimal defects such as knots or other issues. The consistency of colour and grain markings of these boards was also pleasing, the uniformity of the appearance of these boards made matching easy throughout construction.

One thing that is of concern in softer materials are racking strip¹⁰ marks



Image 10: Racking strip marks in *E. nitens*

(Image 10) and this was evident in some of the *E. nitens*. These strip marks can cause problems with compression as well as surface discolouration.

This can lead to significant problems when jointing wide table tops as the racking strip marks tend not to be visible until the finish is applied. Also this can become a costly and an obvious defect in the finished product. The racking strip marks were present although there was little surface disruption and no colour bleed into the timber. The depth that these marks penetrated into the surface of the board was minimal and could be removed in the dressing process. If this form of marking is over 2mm deep then it cannot be removed within the machining process, which causes the marks to become evident later in the finishing process.

¹⁰ Racking strips are used to give separation between boards during the drying process. These strips can leave a depression in the surface of the boards in softer timbers causing loss of thickness of the finished board. Normal dressing (machining) reduces a 25mm board to 19mm when finished.

***E. obliqua*:**

These samples of the *E. obliqua* gave a good comparable cross-section of the attributes and problems that are normally associated within native-forest eucalypt timber. There was a good general spread of density within the sample set and this is representative of the range that would normally be expected in these species.

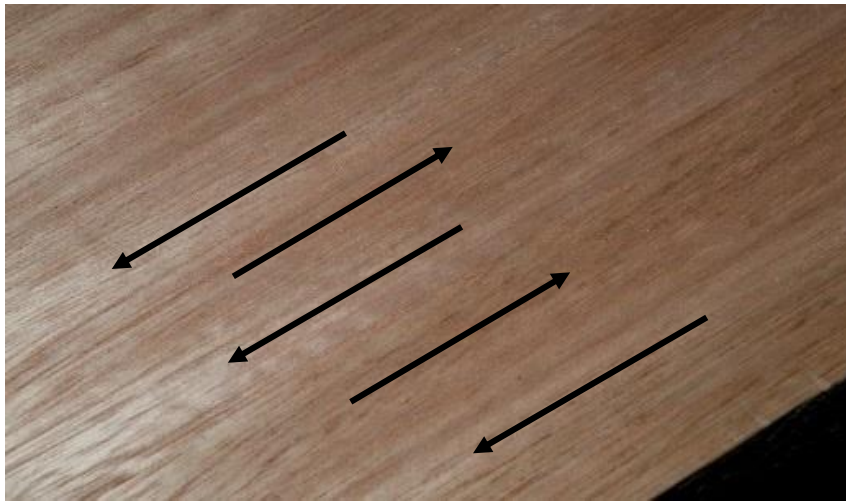


Image 11: *E. obliqua* Ribbon grain

The most common problem with *E. obliqua* in general furniture-making applications is ribbon grain (the grain direction changes in bands across a board - Image 11). This is difficult to deal with as there is no single given grain direction in a piece of material. This means that if the board is planed in one direction, the bands of opposing grain direction across a board tend to tear up, creating a laborious job of scraping and sanding to clean up the surface.

This is an accepted feature of most eucalypts and is a common occurrence in *E. obliqua*. This does, however, come with a positive: there are some attractive decorative elements to this ribbon grain which generally outweigh the negatives. Of interest there was one particular *E. obliqua* board that was lighter in weight than any of the *E. nitens* boards, which

gives an indication that the variation within this species can be significant. The variation within the plantation timbers was far less obvious.

Machining comparisons

In order to standardise as much as possible the testing of the processes of ripping, docking, sanding and turning each species, the tests were carried out using the same techniques and machines. This was done in order to be able to isolate material issues in each species as they arose. The processes were carried out by machining a minimum of 10 random samples from different boards from each species.

The settings of machines is critical. For example, if a crosscutting sample is done with different saw heights the split out can be vastly different. This can also apply to running samples on different days - if a saw has been used to cut a material that deposits a residue of pitch or tannin¹¹ that builds up on the saw in the intervening time the results will vary. To minimise the impacts of machine settings and blade condition on species comparisons, for each machining operation all samples were processed on the same day and with a freshly sharpened saw blade.

Re-sawing

To gauge the re-sawing capabilities of each of the species being tested, it was necessary to cut samples to gauge their reactions. A standard $\frac{3}{4}$ pitch¹² tempered tooth blade was used for this test, (Image 12).

¹¹ The build-up of pitch or tannin on the side of the teeth can cause the blade to cut less efficiently causing splintering.

¹² This refers to the teeth along the blade, $\frac{3}{4}$ pitch relates to the distance between the teeth being 19mm with a 3 set pattern left right and rake with a 2mm kerf.



Image 12: Re-sawing

The results were:

- The *E. nitens* cut well with minimal burst out – a phenomenon that can be an issue with softer materials. The sawn surface was clean with minimal loose fibre which can cause difficulties when deep ripping that produces drag on the saw, thus making it more difficult to rip.
- The *E. globulus* also cut cleanly with minimal surface disruption, and indeed, the *E. globulus* samples cut the best of the three species being compared.
- The *E. obliqua* cut well with less surface disruption than the *E. nitens* but with greater burst out of the bottom of the cut. This is indicative of denser eucalypt wood, and is not a major issue but necessary to note.

There was no noticeable spring, bowing, warping or twisting evident when cutting any of the samples. As timber is hydroscopic the core of any board has a very slightly higher percentage of moisture present this has to equalise. There was no distortion after the samples were left for a few days to stabilise.

This is common practice in cutting laminates and other ripping as the disparity between the inner and outer moisture content of any piece of timber can cause cupping.

End docking

The docking of the samples enabled a more comprehensive look at the internal structure of the timber to see if there were any pipes (internal checks) evident.



Image 13: *E. nitens* End docking

In image 11, the docked ends from the stool legs, from the 33 *E. nitens* off-cuts there were only 5 demonstrating any form of piping present. The 6th sample denoted by the arrow was not a pipe. After closer inspection the mark was a dark Medullary Ray cluster¹³, something that could only be determined in the sawn sample with high magnification inspection.

¹³ These cells are dominant in some species but are present in all timbers.

The docking of the samples did demonstrate that the plantation *E. nitens* and *E. globulus* docked better than the *E. obliqua*. Image 14 demonstrates the burst out, or splintering of the edge of the samples of the *E. obliqua* this was not the case for either of the other species.

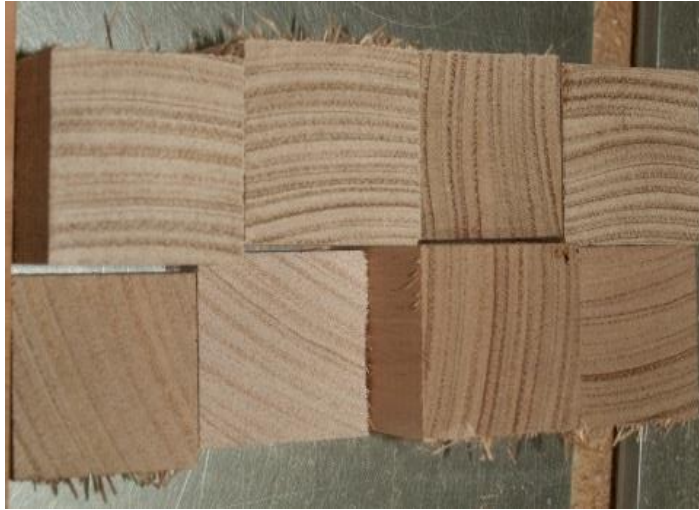


Image 14: *E. obliqua* end docking

The same setup was used on the Panel-saw to cut each of the species, so the results would be comparable. The settings on the panel saw were at the recommended, base of gullet¹⁴ 10mm above the top surface of the material as advised in Joyce (1970) and Walton (1947).

The height of the blade is critical to the outcome of the cut. If the saw is set too high the chip out can be significant. If this standard is not maintained within the comparisons then the results will be inconsistent and misleading.

¹⁴ Gullet refers to the bottom of the tooth

Conclusions of cutting trials:

E. nitens: Given that it is generally softer than the other materials, in the comparison tests it performed better than expected. The density is too low for the traditional *Eucalypt* uses in such as flooring but the way that the material cuts, sands and finishes makes it an ideal material for furniture manufacture. Traditionally local materials such as Blackwood (*Acacia melanoxylon*) have been used in furniture production and have similar spread of density and working characteristics.

E. globulus: Performed the best in the cutting trials, as the evenness of the structure allowed clean and consistent even cuts to be achieved. The comparable minor species that performs in a similar manner would be Myrtle (*Nothofagus cunninghamii*).

E. obliqua: Cut well through the table saw and the bandsaw with the only issues being the slight splintering of the edges. This is a common problem with eucalypt wood and can be alleviated by scoring of the surface to prevent the splintering. The other normal alternative practice is to dress the material first, docking later to clean up the faces; this removes the splintering from the edges but this adds a further process.

Hand planing

This was carried out to compare how the materials reacted to hand planing. The test determines how the grain structure holds together when planed. The shavings are the key indicator of the underlying structure of



Image 15: Hand planing, *E. nitens*, *E. obliqua*, *E. globulus*

the material: if the shavings split apart then this is an indication of some deep level structural issues. There is quite prominent pore structure in the *E. nitens* but this has caused no problems with the dressing or planing process. The comparative shavings show that there were minimal differences between any of the species.

The *E. nitens* planed surprisingly well and left an excellent surface: this was not expected due to the softer structure of the timber.

The *E. obliqua* planed well, producing a clean shaving.

All of the samples tested planed well.

Image 16 shows the sapwood (Bootle 2010, p. 6) present in some of the *E. nitens* samples. This section is structurally sound but has some issues that make it unsuitable for use in furniture. The sapwood tends to block

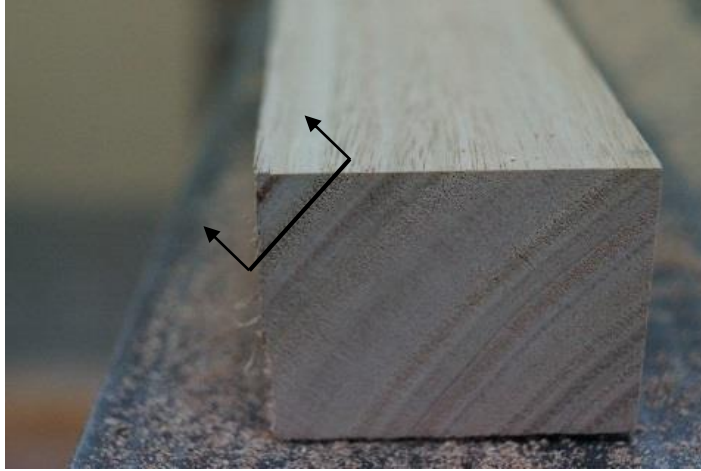


Image 16: Sapwood

dimension sanding belts and in steaming applications tends to display surface checking. Also from observation of all the *E. nitens* samples there was a higher proportion of pipes present in this sapwood section of the boards.

This is also evident in the top two docked ends in Image 13 as these pipes were in the sapwood section. This was common throughout the samples of *E. nitens*.

The sapwood of each of the plantation species worked differently to the heart-wood sections. This was most evident in the planing as well as the turning tests. The sapwood tended to tear more easily and did not react well to sanding.

Surface discolouration as shown in image 17 present in some of the samples is from oxidation¹⁵, which can be caused by a number of factors.

¹⁵ Oxidation is a chemical reaction within the timber accelerated by exposure to sunlight, this usually results in a darkening of the surface of the timber

A likely cause is high levels of glucose and xylose being present in the *E. nitens*.

This is a normal problem in species such as southern Sassafras (*Atherosperma moschatum*) which often displays the same surface staining. The high levels of glucose and xylose in *E. nitens* has been identified in Kibblewhite & Johnson (2001).



Image 17: Surface staining

Wood turning tests

As part of the testing of the overall properties of the plantation species the next process was turning to see how these materials work in production.



Image 18: Dressed lengths

The dressing of the long lengths of the materials is demonstrated in image 18. There were a minimum of 12 lengths of each species machined to form billets for turning.

The *E. nitens* cut on the lathe well in comparison to most eucalypts and there was minimal vibration considering the length and diameter of the material.

Normally there is a degree of tearing on the quarter face but this was not evident in any of the samples that were turned. The cut of the chisel in the *E. nitens* is extremely good and controllable, so the shavings in image 17 demonstrate the timber's ability to cut cleanly.

This type of cut using a skew chisel¹⁶ is difficult to compare to any other eucalypts: the only comparable material in normal usage is pale or pencil Blackwood (*Acacia melanoxylon*). This species shares the same cutting characteristic that the *E. nitens* has exhibited when cut in this manner.



Image 19: *E. Nitens* Shavings

The use of the skew chisel has always been a point of conjecture among wood-turners. Many decry the use of this chisel because it is too prone to catching and ruining the job, however this is usually because they have not mastered its use. This chisel, above all others, is the litmus test for any timber to be machined on a lathe.

Another comparable timber would be *Pinus radiata*. However the grain structure of the pine is different as the annular ring configuration is more prominent, with the spring and summer wood having a greater variation than the *E. nitens* tested.

¹⁶ Skew chisel is a large flat turning chisel ground to a blade point, used to cut long straights or slight tapers. This chisel takes many years to master but is the most efficient way of cutting along a piece of timber being turned. The clean cut from this chisel reduces the need for sanding. The mastering of this chisel is covered in Mike Darlow's article "The Taming of the Skew, subtlety not force, wins favour" Fine Woodworking issue 36 page 70 1982.

The few defects in the *E. nitens* seemed, generally, to have caused minimal problems with the turning. The knots in the surface of the *E. nitens* are harder than the surrounding material and this can cause some pull-out and chipping but this was minimal in the overall turning process even though the examples had to be noted (Image 20).



Image 20: *E. nitens* knot

There was some directional tearing in the *E. nitens* but this only became a problem if there were significant amounts of timber removed rapidly. It is normal in softer materials and can be alleviated by changing the cut to a less aggressive method (cutting with a round faced gouge).

Usually eucalypt timber is difficult to turn as it tends to be splintery but the *E. nitens* was forgiving in the way it worked.

The workability aspects of this material in applications such as turning has been explored within this research project and this has demonstrated the potential to expand the uses of the timber.

Overall the turning of the *E. nitens* reacted better than expected as it was easy to cut and held its shape.

The *E. globulus* sample cut well but with a shorter shaving length - typical of slightly harder material. The plantation *E. globulus* was overall much better to work with than the native forest *E. globulus* as it is not as dense and waxy.



Image 21: *E. globulus* Cutting sample

The softer material with little or no discernible difference between the spring and summer wood made it a better proposition to turn.

The only potential problem demonstrated in the turning test was evidence of more vibration transferred to the surface than the other two species. This is denoted by a rippling effect on the surface of the finished item as



Image 22: *E. globulus* shavings

seen in image 21. This generally occurs in harder timbers so this was not unexpected in the *E. globulus* samples. The peeling of the shavings in Image 21 demonstrates the ability of the *E. globulus* to hold a nice edge. Also clearly visible is the rippling of the surface and this is also exacerbated by the length of the stock as well as the small diameter being turned. The shavings from the *E. globulus* in Image 20 demonstrate the shorter length shaving developed by the same method of cutting.

The *E. obliqua* showed some chipping ahead of the cut which can be a problem in eucalypt but is not uncommon. The *E. obliqua* was prone to larger chips being dislodged during the turning process and this can cause problems if a square shoulder such as a traditional chair leg is being turned. The *E. obliqua* shavings were smaller and slightly more splintered again typical of a denser materials.

Conclusion of the working properties of the plantation eucalypts

The working properties of the plantation eucalypts were in many respects surprising. The *E. nitens* was the surprise packet of the timbers tested as there was no great expectation placed on it prior to receiving the material from Brittons Brothers, as the previous samples were marginal in quality. This was mostly to do with the young age of the trees harvested for the previous trials as reported Beadle et al. (2008) and Innes et al (2008). There were some major drying issues that took place in these trials causing irreparable damage to the material.

Throughout all the working tests within this project, the plantation timbers matched and in some respects surpassed the native forest control.

Most of the differences were subtle but none the less worth noting. Through the testing phase there was not one process that demonstrated any major flaw or inherent deficiency that would lead to failure in any item of furniture made from these plantation timbers.

Gluing and Jointing

As an integral part of this research project it was necessary to determine how the plantation timbers reacted to adhesives. As within the other testing programs the trials were carried out using ten different boards of each species. The aim was to determine an overall average result as there is variation between individual boards.

Adhesive selection

The process of selection of adhesives involved a systematic evaluation of the available glues. Glue choice was based on the following criteria:

1. The adhesives' availability within the general work environment
2. Taking into consideration the target high end processes (some adhesives are only available in large quantities making them unsuitable for small-scale applications)
3. Toxicity: some widely used adhesives are being gradually phased out due to their adverse health effects
4. Within some general adhesive types there are some that can be reactive with species having high tannin levels in their timber. These were identified by comparison and the ones that were most reactive were used to highlight any problems that may occur.

The list of adhesives considered for furniture application were:

1. PVA (Polyvinyl Acetate, broken into their categories)
 - 1.1. Single Aliphatic Rejected (for low end use only)

- 1.2. F9 Rejected (inferior product)
- 1.3. Polymer Modified Rejected (inferior product)
- 1.4. Cross Linked Considered
- 1.5. Molymer Modified Rejected (the addition of the molymer is impractical within small volumes)
2. Styrene (Perbond, Perstick) Considered
3. Urethane Rejected
4. Epoxy
 - 4.1. Liquid (R180, or West System) Rejected (lack of viscosity causes problems in higher soakage into a surface compromising the bond)
 - 4.2. Paste (Epiglue) Considered
5. Urea Formaldehyde Considered (toxic but widely used)
6. Hyde-based (Animal Glue) Rejected (traditional however generally no longer used)
7. Melamine Formaldehyde Rejected (toxic and not widely used due to the health concerns)
8. Phenyl Formaldehyde Rejected (only used in larger production volumes)

After the initial elimination of clearly unsuitable adhesives it was necessary to determine those that would be the most widely accepted and appropriate for furniture applications. To best cover the majority of possible applications without running tests on every adhesive available it was necessary to reduce the number tested to a manageable degree. To this end it was imperative to highlight adhesives that would be appropriate but may also be reactive¹⁷. The process of assessment undertaken relied on my previous experience with all of the adhesives under consideration, to identify the best candidates. This was the list of considered possibilities:

¹⁷ Reactive relates to the reaction between the particular glue and the wood, causing either discolouration or inhibited drying of the adhesive. Some reactions can cause dark green staining in glued surfaces, this does not affect the bond but is unsightly.

1. **PVA (Cross Linking Polyvinyl Acetate)** *Selected*

This product had to be divided into many different types as each form of the adhesive has totally different characteristics. This is because the base Polyvinyl Acetate is made by reacting acetylene and acetic acid and emulsifying in water. The basic chemistry of the adhesive has been modified for many years to improve the performance of the glue. These additional polymers and resins have enhanced the capabilities of the adhesive although these improvements have come at a cost. There can be some reactions to tannin causing discolouration of the glue joint.

Many different forms of the basic Polyvinyl were considered however the final selection (Kleiberit 303.0) is one of the most widely used forms of Cross Linked PVA. The different forms of PVA vary widely in performance, for instance the original form is not even slightly water resistant.

The Polymer Modified form is slightly better in moisture resistance however the Cross Linked is highly water resistant. The other advantages of the Cross Linked form is that it is thermo-set and pressure-activated. This allows the one adhesive to be used for a wider range of applications.

2. **Styrene** *Rejected*

This adhesive was considered but was eventually rejected for a number of reasons. While this glue has good gap filling abilities it also has some drawbacks. The structure of the adhesive is inherently brittle and tends to soak into porous substrates. In previous experiments with this adhesive the bond was not adequate to be used in the trial.

3. **Epoxy** Selected

The form of Epoxy that was chosen was the paste form, as this is more widely used in furniture applications. The other contributing factor in the selection was that the liquid form is prone to soakage in porous timbers.

From previous tests, the liquid form of epoxy is so totally absorbed into the gluing surface there is no material left to bond the joint together.

4. **Urea Formaldehyde** Rejected

This was a difficult decision as this is still one of the best types of wood glue for the majority of furniture applications although the material's toxicity was the deciding factor.

The urea forms of adhesive still have a place in larger applications such as beam and panel construction where the toxicity issues can be controlled. As this adhesive is becoming less popular in general small scale applications it was rejected in the end.

After the initial selection of the adhesive types it was necessary to decide on the manufacturer.

There can be major differences between the basic chemistry of each brand as well as the availability of fresh adhesive. The high-tech Cross Linking Polyvinyls have a short shelf life, and as we in Tasmania are at the end of the supply chain it is necessary to take this into consideration when selecting adhesives. Past experience has been that batches of glue can be at or over their viable age before they are delivered here. Thus it was imperative to use an adhesive that is turned over at a higher rate, insuring viability.

The Kleiberit 303.0 (A) was selected because it is an industrial adhesive used in quantity. This improves the chance that the batches of glue were fresh considering it is imported from Germany. Other Cross Linking Polyvinyl coming in from The United States of America are not used in large enough quantity to ensure the glue is still viable.

The normal test for the “freshness” of the Polyvinyls is to sniff it! Although a somewhat “agricultural” approach, it remains the best method available because, as the glue starts to break down the components start to separate. The basic method of making these adhesives is to react acetylene and acetic acid then emulsify them in water. If the emulsification starts to break down it causes the acetic acid to boil to the top of the drum giving off a “gassy” acidic smell.

There can also be major problems when adhesive has been on shelf for extended periods as it is degraded by heat and the small bottles are particularly prone to this issue. The larger drums are generally better as their temperature remains more stable due to their greater volume.



(A)

Over the last 15 years of personal trials and experimentation Kleiberit 303.0 is the Polyvinyl that has the widest range of applications and has given the best overall results.

Previously tested were: National Adhesives 5400, F9, AV Sintec AV180, Titebond II & III, Selleys Aquadhere and Selleys Aquadhere Exterior.

The drawback of the cross linking adhesives is that they are reactive with some materials such as Blackwood (*Acacia melanoxylon*) as well as some *Eucalyptus* species. The cross linking adhesives are much stronger than the single, double and triple aliphatic Polyvinyls.



(B)

The other glue selected for testing was Epiglue by International Adhesives (B). The reason for this is that it is one of the most trusted epoxies with good penetration and is the one most widely trusted by cabinetmakers and boat builders.

The other reason is that this type of paste epoxy has a superior bond to porous and dense materials. The other types of epoxies tend to be thinner and soak into the material completely compromising the joint.

Adhesive testing method

The final adhesives selected were Kleiberit 303.0 and Epiglue as these represented the most widely used and accepted within the cabinet making field.

These were prepared with identical surfaces as seen in image 23.

As the bonding surfaces had to be identical without a break in the surface, the alignment cuts were made in the edge of the samples indicated by the arrow.

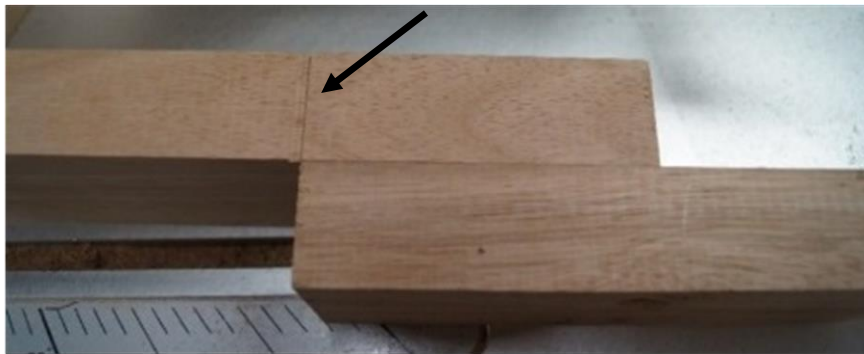


Image 23: Sample Reference point

This was done to ensure that there was no disruption to the surface that was separated. Alignment using cut lines in the wide surface of the block was not used. This break in the surface can cause the block to split from that point, giving a false impression of the break line, whereas the cut in the edge does not compromise the gluing surface.

The line on the side of the sample was used to align the surfaces ensuring the samples were all identical in surface area. As part of the preparation of the destructive test samples the matching surfaces were all machined at the same time, ensuring the surface planer was delivering the same cut surface. This was done to replicate the same surface bond on all samples.

When the adhesive was applied the excess was removed, to enable the samples to break as close to the joint line as possible. Other considerations were the film build-up of the adhesives and the surface coverage. It was important to apply the glue to all surfaces evenly so the bond would be identical.

Another consideration was the time taken to assemble the components as the Cross Linking Polyvinyl forms a skin on the surface rapidly. If the jointing surface is not clamped quickly then the surfaces have started to dry to a point that the bond is compromised.

Image 24 shows the removal of the excess glue from the joint surface. This point proved critical to the results of the testing as there was a clean even surfaces on each side to allow the joints to hold on their merits.



Image 24: Cleaning glue from edge of sample

In previous tests false outcomes had been caused by the extra meniscus remaining after gluing. It is also imperative to remove the glue without wetting as this tends to drive the glue into the surface also giving a false result. Once the glue was dry all of the samples were side dressed to a uniform width to ensure that the glue surfaces were identical.

After the samples had fully cured they were mounted in a vice. From there the samples were hit with a hammer from left to right to fracture the glue line as demonstrated in image 25.



Image 25: Breakage Test

This process was done in the normal workshop manner to determine the bond. There is no need to find the amount of force necessary to break the joint as this is a simple adhesion test to ascertain how the adhesive bonds to the surface.

This methodology may appear crude. Nevertheless it is effective in determining surface bond of each of the adhesives tested. The rationale behind this is to determine if the plantation timbers deviate from the normal expectation of the native forest eucalypts.

With the comparison being carried out between the various samples it was clearly evident that the surface bond obtained with the adhesives used was within acceptable limits on all samples. There were minimal differences in bonding between the Epoxy and the Cross Linking Polyvinyl.



Image 26: Stress test in PVA



Image 27: Stress test in Epoxy

Samples of *E. nitens* image 24 were done with PVA, image 25 with Epoxy. This demonstrated that in the epoxy the bond to the annular ring was greater than the spring wood. Each sample demonstrated good surface penetration and full bond to the surface.

Conclusions from glue testing

There was no evidence of discolouration across the samples tested with any of the adhesives.

The adhesive samples proved that there was good adhesion throughout all of the samples. There were no major failures with any of the samples, although there was slightly better adhesion with the plantation eucalypts in comparison to the *E. obliqua*. This is most likely due to the lower density of the plantation timbers in comparison to the native forest species. The lower density allows the adhesives to penetrate further into the surface increasing the bond.

Limited trial integrating the plantation eucalypts into a teaching program

Another trial using the plantation *E. nitens* and *E. globulus* for a student project demonstrated that the bond in frame construction was comparable to the native forest eucalypts.

There was an opportunity during the period of research to trial some of the plantation *E. nitens* and *E. globulus* in a first year student project. Other observations included:

- The students were able to handle the material with no major differences in comparison to the other mill-run native forest eucalypt normally used for these projects
- There were no problems identified during the dressing and general preparation of the material
- The jointing and gluing was the same as the normal mill-run material, the open time and cramping times were identical to the native forest eucalypts
- Interestingly, the majority of the students could not tell the difference between the three species used even considering the lighter weight of the *E. nitens*
- In the case of the *E. nitens*, the students found it easier to cope with because it sanded better than the other two eucalypts tested.
- The drawback was that the *E. nitens* material being softer, dented and marked easily in comparison to the *E. obliqua* and the *E.*

globulus. This problem was reduced once the timber was sealed with any finish.

Overall the results were encouraging because the unit was the students' first introduction to wood working and they were able to see no difference in the materials other than it was marginally lighter.



Image 28: Jointed frame

Image 28 is of the small exercise frame the students had to produce. This was a test example completed as a demonstration for the class. The jointing and general gluing worked well. The 20 students produced these without any issues: about ten students used the *E. nitens* and the other ten used a mix of *E. regnans*, *E. obliqua* and *E. globulus*. There was no appreciable difference in the instruction to students required for any of the three species.

The other general jointing observation was that the drilling and Domino jointing worked in the same manner as the other species.

The assembly of the joints also posed no problems for the students. The dowelling of some of the frames also demonstrated a difference between the plantation and native forest timbers: importantly, the lower density plantation material was not as prone to errors in drilling into the end grain.

This is a classic problem with timber that has hard annular rings and soft spring wood where the drill will sometimes wander off line. This is



Image 29: *E. nitens* domino slot

caused by the denser summer wood allowing the bit to move during the drilling process as it is difficult to hold the drill on line.

This glancing off the annular ring causes the joint to become misaligned. The softer plantation *E. nitens* and the *E. globulus* were less prone to this movement offline.

Sanding and Finishing

The next test undertaken involved the application of finishes to samples of *E. nitens* and *E. globulus*. This is the record of the normal systematic process that is undertaken when using either an untried timber or finish. This testing process relates to the furniture maker's specific requirements when dealing with a material that has not been encountered before.

An extensive selection process was undertaken prior to the material tests to identify the best finishes to be used. This involved the identification of appropriate finishes that would meet normal requirements but also highlight any pitfalls that may occur. The initial process was to identify available finishes that are used in a contemporary furniture context. This process enabled a reduction in the number of samples needed to give the best spread of possible applications.

1. Traditional

1.1. French Polish (Shellac derived from the *Kerria lacca* beetle with a wood alcohol solvent) Considered

1.2. Furniture Oils

1.2.1. Tung Oil (derived from the *Vernicia fordii* nut) Rejected

1.2.2. Scandinavian Oil (with oxidising dryers such as Terebine) Rejected

1.2.3. Natural Scandinavian Oils (containing Lemon oil oxidiser) Considered

1.3. Polyurethane

1.3.1. Traditional oil based Rejected

1.3.2. Combination Polyurethane and Scandinavian Oil
Considered

1.4. Waxes All rejected

1.4.1. Beeswax

1.4.2. Carnauba Wax

1.4.3. Combined Bees Wax, Carnauba Wax and Pure Gum
Turpentine

1.4.4. Paraffin Wax (petroleum based)

2. Modern

2.1. Nitrocellulose Lacquer

2.1.1. Pre-catalysed Considered

2.1.2. Post- catalysed Rejected

2.2. Moisture cured Polyurethane Rejected

2.3. Clear Acrylic Rejected

3. Contemporary

3.1. Two Pack Polyurethane

3.1.1. European (less toxic) Considered

3.1.2. Australian (containing Monomeric Isocyanates) Rejected

3.2. Water-based Polyurethane Considered

3.3. Epoxy-based clear coatings Considered

3.4. Polyester (water clear) Rejected

The objectives of the selection process were to identify finishes that would be generally accepted and to identify their suitability for this project.

Finishes considered after sorting by relevance

1. French polish (shellac) Rejected

This was rejected because it is not generally used and has a number of associated problems. For instance it is not water resistant and the application of this sort of finish is a specialised field. It is not generally used now that better finishes are available. From prior experience there would have been no problems associated with the application of this finish to any of the samples because shellac is inert and, in many cases, it is used as a barrier coat to isolate reactive elements.

2. Pre-catalysed Nitro Cellulose lacquer Selected

This form of Pre-catalysed lacquer is the most widely used and is accepted as a basic standard of furniture finish. The specifics of brands of this form of lacquer tend to be of little consequence as there are only marginal differences in the products .of any of the leading brands.

3. Acid-catalysed Nitro Cellulose lacquer Rejected

The acid catalysed range of finishes are used in more commercial applications as they are toxic and not generally used outside controlled spray booths because of the safety concerns associated with their use. They would have been the first choice 10 years ago for the finishing of high wear surfaces such as table tops.

However we now have less toxic materials available that are as hard wearing and are easier to use. From previous experience the sulphuric acid used as the catalyst could have reacted with the higher tannin species such the *E. globulus* where the commonly accepted practice would be to use a barrier coat to prevent cross contamination. This reaction normally causes a pink

discolouration of the timber so this type of finish was not selected due to this identified and widely recognized problem.

4. Epoxy based finishes Rejected

The epoxy-based finishes are generally used in external application as they discolour with age and exposure to sunlight. This is generally accepted in external application however is detrimental in the furniture-making context when using lighter timbers.

5. Two pack Polyurethane (brushable) Rejected

As part of the process it was necessary to separate the Polyurethanes into two categories - the sprayable and brushable - as they are quite distinct in their application. The normal use for the brushable forms of epoxy coatings is for flooring applications as they are slower drying and have a higher viscosity. This leads to issues with the application by brush as it leaves brush marks on the surface and is not accepted in the higher value applications.

6. Two-pack Polyurethane (sprayable) Selected

This is generally accepted as a standard in high-end furniture applications as it is hard wearing and archival in quality. The selection of this came down to the different products on the market as they vary in toxicity. Generally, the imported lacquers contain fewer toxic compounds and so they are safer to use. There is a major difference in the expected exposure limits for Australian-produced lacquers versus the imported products in that the locally produced coatings currently don't meet the CSN EN Standards(European Standards).

7. Water-based polyurethane Selected

This finish was selected because this is becoming a more widely used material as the need to reduce the toxicity of materials becomes imperative. This form of timber finish is being refined to work effectively in Australian conditions and has reached wider acceptance among furniture makers over the last few years.

Testing program for finishes

After the selection process it was necessary to move into the testing of the selected finishes on the 3 species. The preparation of boards involved segmenting into 6 separate sections, these sections allowed direct comparisons to be done between each of the selected finishes.



Image 30: Sample Board

The sanding was initially done with the dimension sander then finished off with an orbital sander. The wide belt sanding was carried out with an 80 grit belt and then with an orbital sander with first a 100 grit paper and then finishing off with 180grit.

This is the normal process that I and many others use. It is also normal practice in industry for the preparation of a surface prior to applying finish.



Image 31: Orbital sanding

It is not common to go any finer than 180 grit in sanding as this would shine up the surface causing problems with adhesion to the surface.

The format for the finish test panels was as follows: each panel had a saw cut 3mm deep cut across the grain to prevent any cross contamination between any of the finishes shown in image 30.

As timber is porous finishes tend to bleed along the fibres this can contaminate the next section of the board. Many of these finishes cannot be mixed as they react in undesirable ways giving a false impression of reactions. These cross cuts prevent contamination between the different finishes.

The segmented panels had selected finishes applied to them in this order:

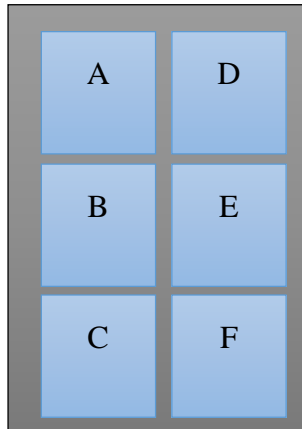


Image 32: Layout, left is the front right the back

(A) Two Pack Polyurethane

The two pack used in this trial was Vernici Egido Milesi 9839/30% with EMC-62 non yellowing catalyst thinned with EM-754.

This form of Polyurethane can cause discolouration in some higher tannin materials and the finish can also be compromised by the waxy surfaces that are present in some eucalypts.

(B) Single Pack Pre-catalysed Nitrocellulose

The product used was Wattyl style wood/ 30%. This is one of the most common finish used in industry and so it was necessary to determine if there were any inherent problems with this finish and how it reacts with the plantation materials.

(C) The application of a spirit-based stain then coated with Single Pack Pre-catalysed Nitrocellulose (Wattyl style wood/ 30%)

This was carried out to demonstrate if there was any soakage issues within the surface. This type of stain is difficult to use as it tends to

highlight problems when parts of the surface repel the stain. Other timber stains can mask issues with the substrate¹⁸.

(D) Water-based polyurethane

The product used was Tasmanian Paints Poly-coat. This polyurethane was selected to check whether there were any issues that arise with tannin bleed or discolouration. The water-based products tend to respond badly to high tannin levels, violently reacting with the surface and producing a change in colour.

The water-based materials are becoming more popular as they have lower toxicity and are more environmentally friendly. But they are slower drying material so there is more potential for surface contamination.

(E) Left in the white (no finish applied)

This was done to act as a comparison with each of the finishes, identifying if there is any significant change of colour from the raw surface.

(F) Oil finish

This was chosen for panel F to test whether there were any significant drying issues, as this can be a problem with porous or hard materials. The Organoil Hard burnishing oil was chosen specifically because it has an oxidising dryer to solidify the surface.

Subsequently a further set of finish tests using a wipe on polyurethane, this was carried out, as the nitrocellulose lacquer when coated onto a

¹⁸ Substrate refers to the generic surface being coated and is a term used in the finishing industry.

piece of furniture proved to be problematic. The milking out¹⁹ of delicate colours caused a flat and lifeless surface to be produced. This can occur with high solids based finishes such as nitrocellulose lacquers.

The full scale surface of the sideboard that forms part of the furniture created in this research project demonstrated this problem and was later stripped and re-finished.

Application of stains

Test panel C had a spirit-based stain applied to it, later a sealing coat of lacquer applied after the stain had dried. This form of stain was selected to specifically highlight any problems that application of a stain to these



Image 33: Stain samples

eucalypts may hold. I used a spirit-based stain because this is notoriously difficult to apply evenly and it will also identifies lower density patches or bands as demonstrated in image 34. It is also common in furniture-making to stain eucalypt darker to emulate other timbers such as

¹⁹ Milking out refers to the masking of the surface caused by some high solids based lacquers. This is caused by high concentrations of various solids used as flattening agents used to decrease gloss levels.

Blackwood as well as even out the range of colours associated with Tasmanian oak.

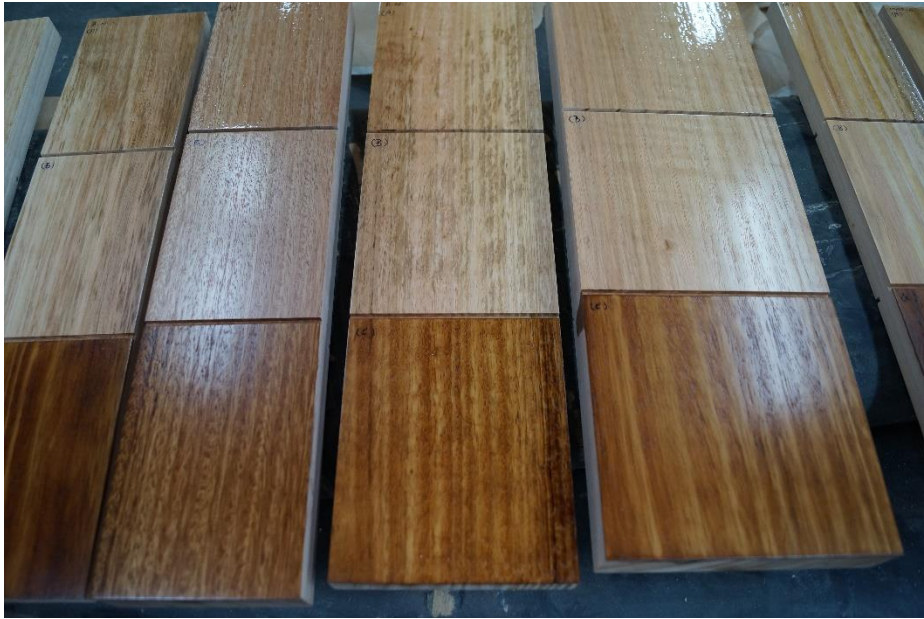


Image 34: finish samples

Conclusions of finishing

Overall the samples of all three came out within the expected range of variations from previous experience with native-forest eucalypts.

They were as follows:

1. The mechanical sanding of the samples was similar for the three species with no major variations in results. The *E. nitens* did show some orbital sander marks but this was only minor and only visible in the stained section. Such marks are normal for any material of this density and can be overcome by sanding with a finer grit.
2. There was no ridging in the *E. nitens* around the annular rings. This is a common problem with softer materials where the annular rings

are slightly harder so that when the material is sanded they tend to stand proud of the surface giving a ridged appearance. This did not occur in any of the *E. nitens* samples.

With the application of the finish, there were no major problems in any of the samples. There were some things that showed up, such as the surface micro-checks in the CRC for Forestry samples which demonstrate an uneven surface finish as the material pulled back²⁰ from the surface crack. The checking was only very minor but as the finish is applied this amplifies the problem. This problem was most evident with two pack polyurethane which has a very high viscosity and build per coat which exacerbates the issue.

- The two pack poly did not adversely react with any of the samples. Only top coatings were used as that is likely to demonstrate any issues with the substrate. The use of under coats tend to mask any problems, as this form of coating is designed to prevent any reactions. Sealers can also cloud the surface as it contains talc as well as some other masking agents. Not all manufacturers use the sealers as they tend to blend out any grain and turn it into a bland and uninteresting surface. So in this case the selected methods were most likely to cause a problem.
- The single pack nitro caused no problems at all on any of the samples.
- The water based polyurethane did react in a minor way by causing a slight darkening of the surface in the *E. globulus* samples, but it

²⁰ The pull back is caused by the wet meniscus formed by the high viscosity finish.

was so minor that it only showed up when a close comparison was done with other samples.

- The oiled surface displayed no problem with any of the samples and there was no inhibiting of the drying of the finish as can be the case with the higher tannin materials.

So overall there were no major or unexpected problems with sanding or applying a finish to any of the samples.

After the selection of the Pre-catalysed nitrocellulose this coating was applied to the sideboard that was displayed in the InForm exhibition. The finish proved to be lifeless under gallery lighting, covering up the timber's natural character. This led to the trial of another finish, Feast Watson Mastertouch Wipe-on Poly.

This finish is a mix of polyurethane and an oil giving it the application method of an oil with the depth of clarity of a slow drying finish. This type of finish soaks into the surface further than a fast drying lacquer giving the extra depth of colour.

Steam bending

Steam-bending reveals more about a material's properties and potential than simple flat panel construction because the structural integrity of the material itself is manipulated. It is possible to tell in a couple of hours how



Image 35: Thonet Factory

a timber will look after the equivalent of decades of life in board form. This equivalent of accelerated ageing is caused by the softening of the bond structure and allows inbuilt tensions and micro cracks to reveal themselves. So, as a technique, testing in this way allows the material to be pushed to its point of near disintegration.

Although steam-bending is a very old technique, the methodology has traditionally been handed down from one generation to the next as the various methods rely more on feel than on science. Steam-bending has predominately been a wooden boat building technique and has usually been crude in its application.

As with most things that rely on the passing down of knowledge, we today are reliant on the information we have recorded, and this is not

necessarily the best that has existed on the subject. The use of steam-bending in the furniture field has been traditionally on a larger scale with heavy machinery used to produce single dimensional bends.

In researching this subject it is worth observing that there has been a reliance on northern hemisphere materials such as beech (*Fagus sylvatica*). This is a material which is very forgiving when it is steamed allowing it to be bent easily.

The use of European beech by Thonet allowed the firm to produce furniture involving curved elements without costly cutting and or shaping. Although Thonet furniture is now considered as iconic, this has to be put into context, because they were the IKEA of their day. The majority of their furniture was sold from catalogue and arrived flat packed to be assembled by the purchaser.

Steam generator

The normal method of producing steam involves the boiling of a fixed volume of water which reduces rapidly giving a variation in the temperature of the steam. This is a critical issue with the conventional method of generating steam, as there is a sweet spot of temperature and humidity that needs to be created. Each time the water level in the vessel drops, the temperature spikes and the steam becomes what is classed as dry steam (over 100 degrees Celsius). This causes the timber to become brittle. Conversely, the drop in temperature caused by topping up the vessel causes the timber to cool down resulting in breakages.

To counteract this variation it was necessary to design and build a steam generator that was capable of being adjusted, allowing the flexibility to adjust the temperature and the volume of water required.

The volume of the water-heating vessel is the most critical component, as it has to contain a large volume of water. This is achieved by having a large vessel of water with a small surface area heated to boiling point, allowing the water to vaporise gently.

The management of the water level in the past for me has been the most problematic aspect as the steam evaporates, so the water level decreases in the tank. The introduction of cold water into the tank immediately stops the water from boiling setting the process back each time.



Image 36: Steam generator

The water level can be kept constant by the introduction of a continuous feed system supplying water to the vessel. The introduction of a self-filling system that can also control the water level was a critical element to the success of the steam generator. One problem that emerged in the construction of this generator is the corrosive nature of steam, causing components to decay. The stainless in the vessel is 316 stainless steel although other components were either plated or a lower grade stainless steel and all of these failed over time. After all of these components were replaced with materials that did not corrode the generator worked faultlessly.

Steam box

Once the initial supply of steam had been resolved the issue of the steam box needed to be considered. There are a number of parameters that need to be met, the general flow of steam through the box as well as drainage needed to be taken into consideration.

The leakage of steam is critical as it allows a flow of steam through the container. If it doesn't have sufficient venting, the box will overheat. The flow through the steam box is considerable as when water is boiled the volume of steam at atmospheric pressure increases by 1600 times. So for every litre of water that is vaporized over one cubic meter of steam is generated.

This expansion has to be allowed for, and venting it in the correct manner is critical. Taking this into consideration the design of the steam box was also critical to allow correct and efficient operation.

Experimentation with differing temperatures as well as differing cross sections of eucalypt was undertaken to sort out the best combination of



Image 37: Steam Box

heat and humidity for each operation. The comparisons were done on a number of timber species as well as wood moisture contents prior to steaming.

These practice bends sorted out the majority of the parameters enabling more educated guesses to be made in differing applications. The peg board enabled sections to be bent around varying radii and be held in place to cool and dry.



Image 38: Peg board table

This experiment worked well and enabled me to get a feel of the material's ability to bend. It was most evident in the bend shown above where it was possible to feel the timber start to release and after the initial resistance there was a point when it, for want of a better term, starts to relax into shape. This was interesting because the normal retaining band that stops breakout was not necessary.

This particular process explores the possibility of coaxing the timber into the bends without the use of backing straps – an experiment that decreases the crushing on the inside edge of the radius. This folding of the fibres is evident if one analyses the tight bends on such chairs as the Thonet 214 and is demonstrated by creasing of the internal section.

Secondary experiments involving twisting

Following on from this a number of alternatives arose, one was twisting the timber to use as components.

Twisting will enable the change in the direction of any bends as wood can only be bent in one direction at one time, much as you can with paper. To develop this I decided to try to twist some small scale samples. These were very promising and encouraged me to consider the possibilities of taking the form to a larger scale.



Image 39: Twist models

Experimentation with differing temperatures as well as differing cross sections of eucalypt was undertaken to sort out the best combination of heat and humidity for each operation. The comparisons were done on a number of timber species as well as wood moisture contents prior to steaming



Image 40: Full size twist

The decision was made to scale the form up to full size, so a larger steam box was built with sufficient internal dimension to allow the timber to rotate 360 degrees.

This system had to achieve a number of things: it had to index as well as allow for the change in length of the material as it was twisted.

The box ended up around 5.8m long with an external ratchet system on both ends. An ‘arbor’ – a metal clamping system attached to the ratchet holds the timber under pressure in the box and can be manually turned

when the steam is introduced to the steaming chamber. Observations were that the box had to be bolted to the posts in the workshop as the pressure in the twisting motion produced so much strain that the retuning brackets broke. It had to be reworked to strengthen its components, other than that it all worked as expected. With a pair of boards steamed and bent together, this gave support to each throughout the process.

The most satisfying aspect of this research was that the pre-stressing of the material in the new jig worked well, enabling the ability to increase the twist gently. The relaxing of the material into the form is the most interesting aspect to this.

The possibilities for use of twisted boards as a raw material to create pieces of furniture such as the twisted lamps was the most promising outcome to this process.

Modifications to the twisting jig

The stresses formed in twisting created a number of problems; foremost of these is the indexing head which had to be redesigned to accommodate the pressures involved.



Image 41: Splitting caused by the timber becoming too soft

This splitting in image 41 was caused by the material becoming too soft as it has insufficient structural integrity to hold against the forces that are applied to it. There was a fine line between maintaining the integrity of the material and softening it sufficiently to allow distortion.

The CAD drawing image 42 of the steamer end was modified to allow left and right rotation. As a result I have done a matched pair of left and right twists with the one jig.

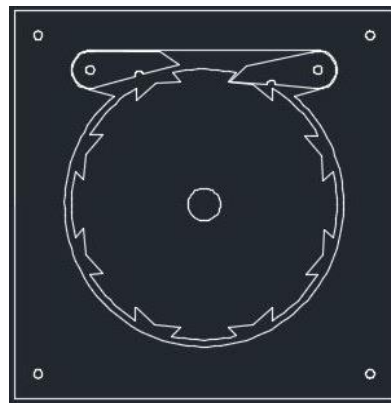


Image 42: CAD Drawing

The continuous resistance to the bending force within the material allowed the slow process of steam-bending to form interesting shapes. As well as forming a twist an added benefit was that it formed a slight cupping within the boards.



Image 43: Modified twisting jig

This adds a second dimension to the shapes derived from this process. This is one of the most pleasing aspects to the results. The problem with this methodology was that there was a high proportion of breakages and this caused the process to be shelved for some time (two years).

Modified steaming process (plastic bag bending)

This method of steam-bending was discovered by one of my fellow students, Sara Lindsay, (<https://www.youtube.com/watch?v=--iPQIwSEJM>. Viewed 27-01-2016). The clip on steam-bending shows a shipwright, Louis Sauzedde of Wickford, Rhode Island, bending a plank onto a dingy in a plastic bag. The method flies in the face of conventional thinking as the normal practice is to use a heavily insulated steam box to maintain heat in the material.

The initial impression of the method was it should not work, however it does. This came as a revelation after testing the output of the steamer starting with a 2m length of bag then moving to a 6m length of tube. There was no appreciable drop in temperature from one end of the bag to the other.



Image 44: 6 m length of plastic tube

The image shows the 90mm diameter plastic bag, the temperature was 95 °C at the steamer end and 92 °C at the end of the 6 m of plastic. This led to a re-thinking of the steaming section of the project as this shift in methodology opened up possibilities and design ideas not achievable with existing technology.

The twisting of timber within the bag allows a visual check on the progress of the bend throughout the process.



Image 45: Temperature check during the bending process

There have been a number of interesting observations made during this process:

1. The bag allows visual monitoring of progression during the bending process.
2. The plastic masks the smell of the timber; this is normally used to determine if the timber is ready to bend
3. The bag allows the user to see when the timber starts to effervesce - the board starts to get hot enough to have steam erupt from its surface. This denotes that there is sufficient heat generated within the bag to penetrate through the board.

These observations led to a number of modifications to the process:

1. Pre-soaking in the bag of the pair of boards being twisted
2. Locking together of the boards by a wire and cap system, thus stopping the edge fracturing of the material
3. Better observation of the process due to the clear plastic bag
4. Better retention of wet steam around the boards as the larger the enclosure the greater volume that has to be heated. This method reduces the volume to the minimum required.

These modifications have led to greater control over the temperatures and moisture content of the boards, decreasing the rate of breakages dramatically. The process has a number of other possible applications where timber needs to be bent on site.



Image 46: Matched pair of twists

The native-forest *E. obliqua* did not bend as well as the other species and it is difficult to determine the exact reason for this but the results were constant throughout the steaming tests.

Conclusion: issues and opportunities

The testing and trials of differing methodologies were used to determine if there were any major issues in using the plantation eucalypts for fine furniture.

Throughout the intensive testing program the plantation-grown timbers reacted as well, if not better, than the native forest benchmark. There were a number of situations where the plantation timbers allowed techniques to be pushed further than the bench-mark species.

1. The plantation timbers twisted better than the native-forest eucalypt, with less spring-back.
2. There was much less surface fracturing in the plantation timbers in comparison to the native-forest species.
3. The number of breakages was less with the plantation species compared to the *E. obliqua*.

This enabled items such as twisted lamps to be produced without the problems associated with the more rigid structure of the native forest samples. This freedom to manipulate the plantation material has enabled the production of curves and bends that are tighter with less problems than the native forest timber.

Chapter 3: Applying the methodologies to make furniture

Applying the methodologies detailed in the study, timber from *E. nitens* and *E. globulus* plantation sawlogs was found to be ideally suited to the manufacturing of fine furniture. The testing program revealed that in some respects, these plantation timbers were superior to regrowth native-forest *E. obliqua*.

These conclusions are confirmed by a display of fine furniture items produced in sets of three to demonstrate the practical outcomes for each species

Furniture produced in sets of three

- . Occasional tables
- . Twisted light
- . Twisted lamps
- . Stools
- . Turned platters
- . Steam-bent bowls
- . Machined boxes

In addition, one sideboard was produced using *E. nitens* timber.

Occasional Table

The first item of furniture produced using the three selected timbers was an occasional table which drew its inspiration from an early twentieth century chair created in Tasmania, the Jimmy Possum chair (Image 47).



Image 47

The leg design of the Jimmy Possum chair is where it gains its strength using the triangulation of the intersection between the arm and seat.

An initial impetus for the occasional tables was to study how the eucalypt timbers reacted when jointed over larger surfaces. This also covered processes such as widening joints.²¹



Image 48

The CAD²² illustrated in image 49 demonstrates the methodology applied to gain a quick and easy look at the concept although this is only a preface to the actual making of the object. It is a screen representation that enables the angles to be determined and jigs to be constructed

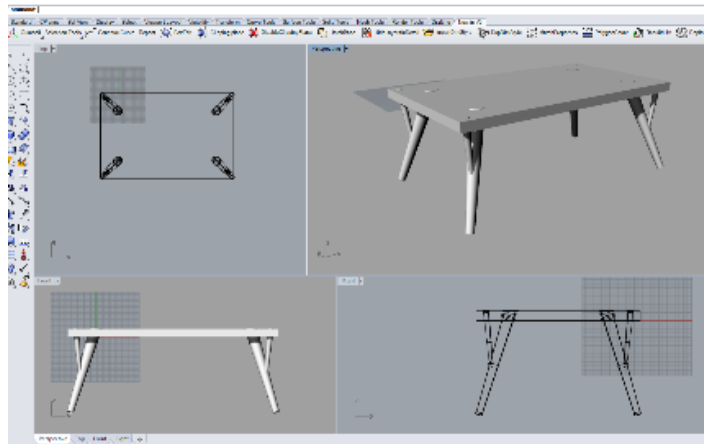


Image 49

²¹ Widening joints are the method of jointing individual boards to form larger boards for table tops or any other application. There is a crucial part to the jointing of wider boards, the allowance for movement within the timber. This is done by hollow planning the joint, this is the removal of a small amount of material from the centre of the jointing surface. This allows the joint to be glued under constant tension this allows the panel to expand and contract but always maintains a degree of force on the ends of the jointing surface.

²² CAD drawing, stands for Computer Aided Design, The software that I normally use is either Rhino or AutoCad. Rhino is used for fast and dirty concept drawings with AutoCad used for accurate 2D drawings.

accurately. This is, of course, only a starting point for the concept which has to be refined as a full sized mockup is developed.

In this particular case the material for each top was docked then skim-dressed to dimension. Then the hand planing of the boards was done to form the hollow jointing surface.



Image 50: Dressed Boards prior to jointing

Selection of the material was done based on the boards as they came from the storage rack; there was no deliberate selection of boards. There was some matching of resulting boards, blending differences in grain markings amongst the docked material.

This was done to maintain the random nature of the materials so that any faults were there to be coped with rather than rejected prior to machining.



Image 51: Gluing table tops

The clamping of the boards was done with sash clamps²³ as they put even pressure on the jointed surfaces. These were used in the configuration in image 51 to counteract the pressures applied. The adhesive used for this jointing was the Kleiberit 303 cross-linking PVA. This is a general single pack adhesive that previous trials found to be the most appropriate for this application.

The drilling of the holes in the top became an issue, as the drill bits tended to glance off line because of the angle that the holes were drilled at. This caused them to become oval and tear out the upper edge of the hole.



Image 52: Angle jig setting angles for holes



Image 53: Side view of angle jig

²³ Sash clamps, are a traditional T bar clamp developed for window and door making.

This was a major issue with this design as each of the holes is angled to differing degrees. The solution was to rout the holes rather than drill them; an angled jig was constructed to tilt the router to varying degrees. This jig could be reversed and, as it mounted on the corner of the top there was no need to mark each individual hole as the jig set the angle as well as the placement.

There were overlay templates made to produce differing diameters and as the reference is the outer edge of the router, the same base jig could be used for holes starting from 19mm up to 70mm.

This type of jig can also be reversed to produce the outer splaying holes as well as the inward angles of the support rail.

This table proved to be a viable design and demonstrated the possibility that flat panel construction in these plantation eucalypts may offer. The prototype used *E. nitens* for the top with the legs of *E. globulus*. This



Image 54: Finished prototype

was done to reference the original that used a mix of eucalypt species. For the final submission there are three identical tables, one from each of the target species.

Sideboard

The sideboard arose from a modification to the occasional table design. This particular piece was done for an exhibition called Inform²⁴ which was an exhibition of the work of 20 local designers and makers focusing on the use of eucalypt in their practice.

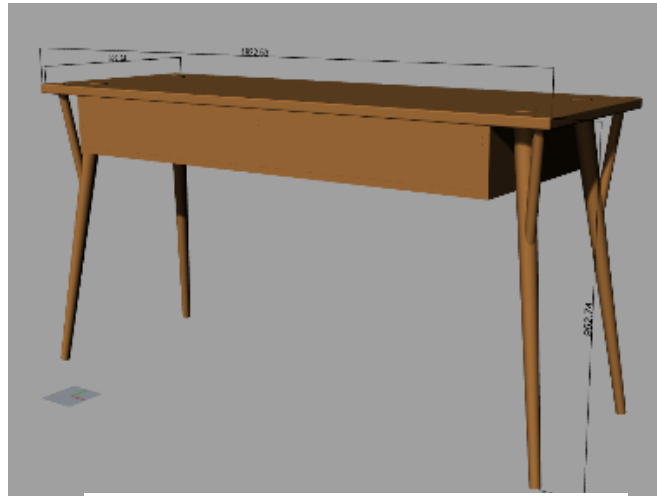


Image 55: CAD Rendering of Sideboard

This was a great opportunity for the material to be showcased in this manner, as this was a dedicated exhibition by local designers and makers specifically addressing the use of a timber traditionally used for floors and other construction based activities rather than for fine furniture.

The sideboard done for this was made entirely from *E. nitens*: the premise of this piece was to use traditional high-end craft techniques assessing the material's suitability for this application. This included the hand cutting of dovetailed drawers as well as secret mitred dovetails²⁵ on the casing of the drawers. This was a twofold approach, as the strength

²⁴ <https://www.facebook.com/Inform-exhibition-737421166294117/>

²⁵ This is a traditional jointing system used when great strength is required but the visually disrupted surface of a dovetailed joint is not wanted.

necessary to support the hanging structure required a strong box joint as well as a visual consideration for the carcass.²⁶

The CAD drawing enabled basic overall measurements to be determined and solve issues such as the angles of the legs. The jig used for the dowel holes in the occasional table tops was employed for this piece. With the addition of a different template guide the jig was able to cut a 70mm diameter hole for the legs of the sideboard.

The top was prepared in the same manner as the occasional tables, with the boards randomly selected but visually graded together to make them flow as one. This matching is a matter of turning boards over and around to find the most appealing match.

The jointing system used on the bottom edge of the draw carcass was also an opportunity to see how the material reacted to blind socket joints. This form of joint requires a fair amount of chiselling as hand saws cannot cut into a blind corner. The material reacted well to the sawing and chiselling giving a clean and even jointing surface. The process of hand cutting was done by eye, there was no placement or angle lines drawn as guides to aid cutting.

As this form of joint is not seen there is no need to be accurate in the spacing or angles of the dovetails. This works out well as the matched sets will only fit one way.



Image 56: Process of fitting edge of joint

Image 57: Side view of secret mitred

²⁶ This refers to the structure containing drawers or doors in cabinet making.

The jointing system of dowelling the legs and support rails through the top involved fastening the intersection with a trennel²⁷ as this form of joint holds fast.



Image 58: Flushing legs down to top surface



Image 59: Detail of dovetailing drawers

The addition of a fox tail wedge²⁸ completed the locked structure of the leg. The only issue with this form of jointing is there is only one chance to get it right.

If the dowel is too long it does not seat, requiring the entire joint to be done again. However if this is done correctly then the results are worth the effort and risk. After the dowelling was completed the assembly was done and legs flushed off to the top. The drawers that completed this piece of furniture were made in the traditional manner with each of the components fitted into the openings prior to the joints being cut.

²⁷ Trennel is the shortened term for Treenail, this is a timber dowel tapered on one end and driven into the meeting surfaces then wedged from the back. The first record of these is in the Khufu ship 2,500 BC used with a mix of copper nails. Later the Vikings used the same method to hold the keels on the long ships.

²⁸ Fox tail wedges are a blind wedge that a dowel is driven onto expanding the bottom of the dowel and locking the joint structure.

These drawers were then glued and refitted into the openings, this requires little fitting as the components have been in the opening previously. The drawer bottoms were done out of solid material as this fitted with the traditional methodology.



Image 60: Finished Sideboard

Twisted light

This design started as a test to see if eucalypt could be deformed into a twisted structure; the pairing of elements allowed the twist to become a self-supporting entity. If only one section was twisted then the rotations were uneven; done as a pair, both lengths gave sufficient resistance helping keep the form even.

This proved to be the case when the experiment was scaled to full size. The reaction of the material worked out to be proportional to the cross section. In the early testing, taking the material to full size whilst



Image 61: Primary experiments with twisting

maintaining heat proved to be difficult, particularly over the length of the board. This required the manufacture of a large steam box housing the material whilst steam was applied, which allowed the temperature to be maintained, as described in Chapter 2.

Unfortunately this led to inconsistent results; the box being closed did not enable any monitoring of the progress during the bending process. There were some successes, however also some catastrophic breakages. There was no difference between any of the species, they all had the same issues. The one good pair resulting from the trials was made into a single light.

This proved to be reasonably successful although there were a number of observations from this trial, the removal of a rebate from the centre of the board resulted in the loss of about 50% of the twist.



Image 62: First successful twist

The resulting light did perform in the way it was intended, but the loss of rotation proved to be counterproductive, changing the overall appeal of the light. The boards were set apart by 15mm with the inner part sprayed in two-pack white paint to improve the light transfer, this worked effectively. Having 300 LED lights mounted down the centre of the 4.5m length of the twists, emitted sufficient light to make the statement required. The barley-sugar style twist worked given the output of light, however the inconsistencies in repeatability caused this design to be shelved awaiting a solution.

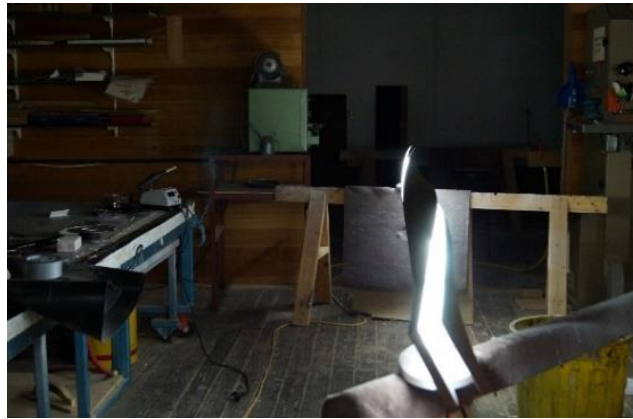


Image 63: Completed light

The solution of the plastic bag bending method mentioned in Chapter 2 produced consistent twists that were later incorporated in the twisted lamps described below.

Twisted lamps

The twisted lamps were on hold for some considerable time because the twisting process was not repeatable with any degree of certainty.

The addition of the plastic bag steam-bending process described in Chapter 2 has enabled this design to take shape.

The initial idea for these lights was a vertical version of the twisted ceiling light, this was modified for a number of reasons. The removal of material from the centre of the twists uncoils the twist, also the LED²⁹ light was not as concentrated as it could have been, and this led to examination of at other options.

²⁹

LED, Light Emitting Diode an electronic component that generates light with minimal heat generation. This form of lighting is becoming more popular as it is highly efficient in terms of light output per unit of electrical energy consumed.

After the resolution to the bending issues the possibility of modifying the configuration became feasible. The first experiment was on some shattered offcuts to gauge other means of mounting or jointing the twisted elements image 64.



Image 64: Trial of jointing curved

This proved to be possible; the only catch was to cut a mitre on the edge of a helical board, as this had to be done after the steaming process because the edge would not stand being twisted. The problem with steaming material that comes to a sharp angle is the stresses are uneven, and the thin edge would have separated or at best not retained its shape. Subsequently a method of cutting the edge of the pre-steamed board was developed, using a jig on the bandsaw.



Image 65: Cutting joint on twists

This jig had to retain the timber yet cope with the uneven cross-section that the steaming process develops. This was done by reducing the contact points to a minimum and using a reference point as close as possible to the edge being cut.

There were a number of different configurations tried before settling on the cradle form of the jig.



Image 66: Close-up of bandsaw jig

The main issue was the curvature in the cross-section of the board as this made it difficult to maintain a constant accurate registration point. The resulting cut was reasonably accurate, however there were some alignment difficulties.

These were manageable and allowed the majority of the material to be removed from the jointing surface. Having the twist supported at only one point did present some challenges as once a cut had commenced it could not be stopped, this created an interesting challenge in maintaining the cut throughout the length of the twist.

If the flow of the cut was not maintained this resulted in deviations that made the next phase of the jointing difficult. The offcut from this process was later used to support the centre of the joint.

The time consuming part of the jointing process turned out to be the final fitting of the jointing surface. This proved to be a challenge, as the angle could not be checked with a sliding bevel³⁰ due to the curved surface of the board.

Eventually the most effective method of fitting this joint was by eye, taking a best guess at the required angle and shaping it with a spoke shave.



Image 67: Fitting the joints by eye

This tool is not normally associated with fitting jointing surfaces as it has a short sole³¹ although this is the only reason that the spoke shave worked in the end.

The short engagement surface allowed the tool to cut, all of the other planing tools did not compensate for the curvature of the jointing surface.

³⁰ Sliding bevel is a tool used to check angles other than 45 or 90 degrees.

³¹ Sole of a plane or spoke shave is the surface that comes in contact with the material giving the tool a reference surface to gauge the degree of the cut.

The actual jointing of components required the best guess at the angle required then these components had to be fitted together with specially designed clamping cauls³² to hold the components together.



Image 68: Clamping Cauls with folding wedges

The problem with this was that the variations within the steam bent boards as the distortion occurred was causing the cauls to become difficult to use.



Image 69: Clamping Cauls pulling joint together demonstrating how the jig re-aligns the components

³² Clamping cauls allow pressure to be applied to specific points of the jointing surface.

The solution was to have cauls with wider tolerance allowing for the cupping and other variations. The cauls were slid along the length of the light then folding wedges³³ were driven in to clamp the form together.

The advantage of this system is that it is light in weight and thus many of them can be used without the problems associated with heavy steel clamps.

Without the use of these cauls this particular glue-up would have been impossible. The amount of direct force possible with each one of cauls is equivalent to at least four conventional clamps.



Image 70: Matched pairs in each species

³³ Folding wedges, this type of paired configuration of wedges allows pressure to be applied to specific points of a joint and as the wedges are identical in taper when they are driven in they expand parallel.

On this particular twisted lamp, 32 steel clamps would have had to be used in sequence whereas the clamping cauls and wedges reduced the number of clamps considerably. The amount of force that was necessary to pull this twisted form into alignment was considerable as the components had to be slid into place. As image 69 shows, the degree that the two boards had to be pushed back into alignment also made the final fitting difficult as the components had to be completely held in shape to see if the joint was indeed correct.

So the process of fitting entailed the twists being put together at least five times before they were ready for glueing. Once the first two components were glued then the strip was glued down the centre of the joint, then the back section was added. This joint was possibly the hardest to do as the



Image 71: Cross section showing the joint in the process of being cut with the draw knife

mitre joints had to be done with a drawknife³⁴. This was the only tool that could get into the corner effectively; this tool is not usually used for jointing. The fitting of this joint relied on trial and error to finally get the two components to meet correctly. Again, this had to be done by feel as

³⁴

Drawknife, double handled flat blade tool used by wheelwrights, bodgers and chair makers.



Image 72: Finished *E*.

there is no reference points that could be used as guides. The light used to illuminate these lamps was an LED pool light as it had a good spread of light within its beam diameter. A number of light sources trialled but this was the only one that worked adequately. These lamps worked well as the form changes from all angles and, while simple, has elements that intrigue the viewer.

Stools

There were a number of seat configurations tried for the stools; the first was an upholstered top. This was rejected as there is no other coloured elements within the work being submitted.



Image 73: Prototype

The choice was made to use a solid seat, and this was also an opportunity to trial another turning process.

The stools were an opportunity to test the timbers in a number of ways. The legs were turned, then steam bent, which enabled a tighter bend to be achieved as there was a smaller dimension being bent. The drawback of this was that there were a number of legs broken in this process.

It took some time to work out the correct method to bend these legs as the initial problems revolved around getting sufficient heat into the core of the leg. This was eventually achieved by soaking them in water for a day prior to steaming. This allowed the heat to penetrate into the leg right to the core, this decreased the failure rate dramatically.



Image 74: Vacuum bag being sealed

The seat top was turned with the dowel holes pre-drilled to enable accurate spacing to be maintained.

The footrest allowed me to experiment with a lamination process which I had devised during the project. Typically, laminates need some form of template together with steel clamps to enable the timber to be curved or hooped into a circle. The process I developed was to glue up the laminates and, while still flexible, to compress the form using a vacuum bag; this was followed immediately by bending the cladded timber

laminates around the appropriate template - in this case a circular mould. The vacuum bag holds the laminations together without the necessity to use excessive numbers of steel clamps. Once the circle has been stabilised and the glue has set, the ends are scarfed together to form a

complete hoop, notches are cut into the legs to form a joint locating the footrest, and the hoop is locked into place. Images 74, 75 and 76 illustrate the process.

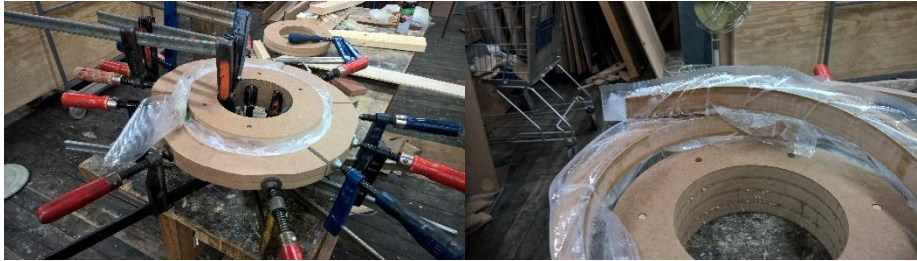


Image 75: Vacuum bag being formed into helix

One difficult part of this was the wedges in the top of the legs, which had to be placed in the correct orientation. This is hard to achieve as there are a number of things that can twist the leg slightly during gluing, and this would have spoilt the symmetrical placement of the wedges in the seat.



Image 76: Notch cut into leg to locate hoop

Once the components were dry fitted together each piece was removed and finish sanded prior to gluing. This ensured that each component remained in its allotted position, then the trennels were fitted.



Image 77: Notch cut into leg to locate hoop

These stools worked well, although the only difficulty was in the bending of the *E. obliqua* which proved to be challenge. There were eight legs bent to achieve four that were passable. The other species performed more successfully in the bending process.

Turned platters

As part of the investigation into these materials it was prudent to trial cross-grain turning, and this was done by turning a number of platters. These are a standard way of showing off a timber, as the cutting across



Image 78: Attaching blocks to the face of the platters

the grain exposes a form of figuring normally hidden within the surface. The cutting across the fibres also reveals any inherent issues within the material. When turning timber in this manner each rotation exposes the chisel to end grain and side grain, opening the possibility of tearing the fibres on two opposed quadrants. The preparation of the blanks was done with a block glued on the front face to attach the blank to the lathe.



Image 79: Turning the back surface of the platter

This block in some cases is glued on with paper in the joint to make it easier to remove, however in this case it was not necessary. The grain direction of this block is placed at 90 degrees to help reinforce the platter during the turning process.

The turning of the front of the platter is done by using a friction fit face plate³⁵. Once the recess is fitted the platter can be finished.



Image 80: Friction face plate being fitted

The face of these platters is the difficult part of the operation as they have to be hemispherical and this is tricky to achieve as the speed varies across the surface being turned. The centre of the platter is stationary and the periphery is traveling rapidly.



Image 81: Figured and plane *E. nitens*

³⁵

Friction fit face plate is a method of holding turned work that leaves no marks on the item being turned. The recess into the backing board has to be fitted with a tolerance between .1-.2 mm.

This causes the cut to be more efficient towards the outside of the platter leaving the centre as a bulge.

The turning of the platters revealed some pleasing figuring, and a surprising resilience to the buckling that is quite common when turning forms using minor species.

Steam bent bowls

This was an experiment in single dimensional bends using the plastic bag steaming method.

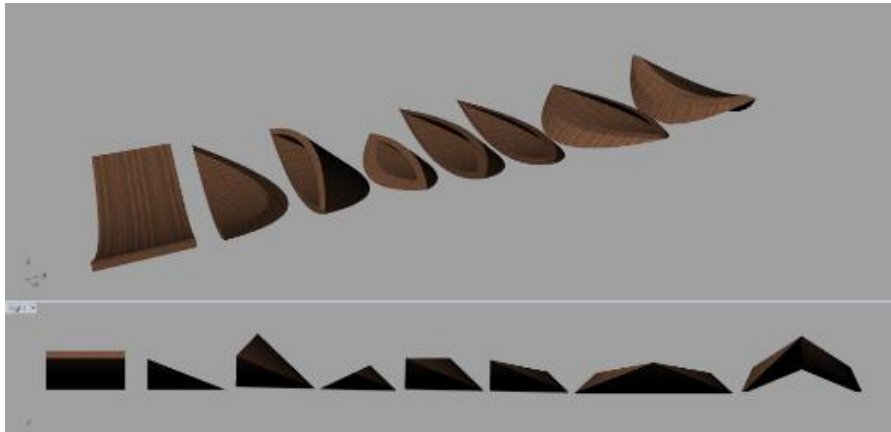


Image 82: CNC rendering of steam bent bowls

This proved to be effective in producing a significant curve in a pair of 150mm x 15mm boards. The primary idea was to make pods using the curved boards, then doing several cuts and re-assembling to form other shapes.

The process proved to be problematic as the forms were too small to be effective. A set was produced, but after the first cuts it became obvious that the volume of the shape became prohibitively small. The first set of



Image 83: Mock-up of first design

actual bends were cut to form the primary shape however they a large exterior shape with little internal volume.

The opening became so small as to look proportionally incorrect and lost all of its appeal. Subsequently this design changed using the primary bends and creating a minimal mitre cut down the centre to produce a large flatter bowl form.

This proved to be a more aesthetically pleasing minimal form with facets cut on the base to allow the bowl to be placed

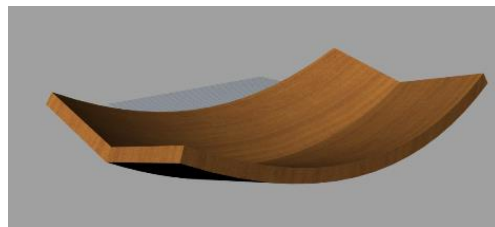


Image 84: CNC render of second design

on several different angles. The bending process was successful in



Image 85: Steam bent prototype

producing a number of good quality bends enabling prototypes to be produced. Having the boards mitred together proved to be an effective method of producing an attractive product.

Machined boxes

As part of the project it was necessary to run tests on how the material reacted to routing. This is a process that in some eucalypts can be problematic, as there can be glazing of the cutter caused by tannins. This can cause the surface to be poorly cut restricting the possible applications. As the use of Computer Numerical Control (CNC) routing is becoming wide spread in the furniture industry this test required attention.

The design of the box is based on the offset, slightly concave representation of the plan of the twisted lamps. As with most of the planning process a sketch is done then as this is a purely mechanical operation the rendered drawing is produced.

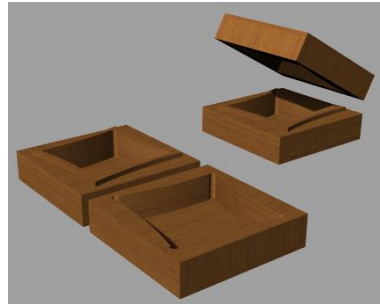


Image 86: CNC rendering of boxes

The Rhino software package is used for the basic drawing with rendered images which are then exported to Autocad to confirm correct two dimensional line configuration. Files are then imported into a tool pathing package to develop the G code (this is the coordinate based code) allowing the track of the cutter to be generated.

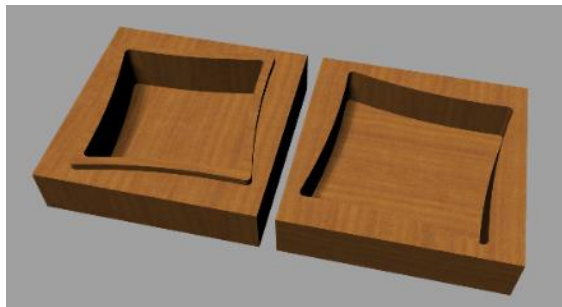


Image 87: CNC render of final design

The software that I use for this is EnRoute³⁶ which allows the input of depths and cutter speeds to be determined. The offset for corners is done in two ways; one is to allow the corners to be removed as Image 85 denotes.



Image 88: CNC routing of the prototype box

Second is noted in the drawing Image 89 that has the corners rounded off to allow the cutter to track directly into the corners.

Either of these methods work but, in this case, the radius of the corners was confirmed by the toolpath generation as the most effective solution. The three machined sample boxes are shown in Image 92 prior to fitting and sanding, the cut-out is done then final hand fitting is necessary. The tolerance for the machine does not allow for fibre compression³⁷ from the cutter, the hard material is tighter than the softer materials.



Image 89: CNC cut final versions in, *E. globulus*, *E. obliqua*, *E. nitens*

³⁶ EnRoute is a tool-pathing software package that generates the G code that CNC, Computer Numerical Machines require to cut out any shapes.

³⁷ Fibre compression by cutters is a problem in soft timbers as the router bit compresses the surface, this causes the fitting to become a problem.

The use of any CNC equipment requires a different set of skills from normal cabinetry. The skill and ability required to manipulate the material has been transferred into the virtual world rather than the physical.

The prior planning and preparation of a drawing if done correctly achieves a superior result from the machine. If drawings are poorly prepared the machine struggles to interpret the path, causing slower or varied feed speeds to be generated resulting in substandard results. This preparation is similar to that of any hand making process where if the step by step processes are followed the result is assured.

As with the handmade process, if the correct sequence is not followed results become variable.

The CNC machining of each of the sample boxes did demonstrate some differences between the species. The *E. nitens* had to be machined in a different order than the other species, this was due to long grain separation on the final cut. This can be a problem if the material is soft causing the cutter to displace, or push sideways material being routed.

This becomes a problem in a final cut around an edge as the waste tends to form a tear extending beyond the boundaries of the cut. This can be overcome by re ordering the cut direction, this is classed as a climb cut. Other than a slight problem with edges in the *E. nitens* all of the other samples performed well.

As noted at the beginning of Chapter 3, the suites of furniture items and objects were developed in order to demonstrate the suitability of the plantation timbers and the regrowth eucalypt control, for high-end timber manufacture. Manufacture of this range of pieces required the full range

of procedures that were tested for the three timbers in Chapter 2. For the most part the techniques employed could be relatively easily replicated by the skilled craftsman or woman, although some techniques, such as the finishing of the twisted lamps, rely on a considerable degree of tacit knowledge accumulated over many years.

What has emerged from this part of the project is that the plantation-grown *E.nitens* and *E. globulus* performed very well even when the timbers were stretched to the limits of their capacity. It should be noted, too, that the regrowth *E. obliqua* proved to be resilient under often testing conditions.

What has been particularly pleasing has been the overall quality and workability of the plantation eucalypt timbers that have been made available for this project.

Chapter 4 : overview of findings

Primary research questions:

1. Do the plantation timbers differ in their processing characteristics from the Tasmanian native forest eucalypt timber currently available for furniture manufacture?
2. Can existing furniture-making techniques be altered to cope with the more open structure of the plantation materials?
3. Can timber from Tasmanian plantation-grown sawlogs be used for the production of high quality furniture?
4. Can these plantation eucalypt timber be formed into flowing shapes utilizing steam-bending as produced by manufacturers such as Thonet?

Answers to research questions

The major question is, can plantation eucalypt timber be used to produce high quality furniture. The answer is, yes they can.

The comprehensive testing done in this project confirms that there are no secondary processing problems which would rule out the plantation-grown *E. nitens* and the *E. globulus* timber that I studied as viable timbers for production of high-grade furniture. The sample furniture produced within this project highlights the potential of these materials and addresses most of the questions relating to their suitability for these

purposes. In many respects the plantation timbers were more suitable for the production of furniture than the regrowth native forest *E. obliqua* timber that was included as a control. The native forest-grown eucalypt timber was marginally harder to work with and heavier than the plantation timbers, in furniture this can be detrimental to the item. The higher density materials tend to be more difficult to glue, and generally the denser timbers lead to items being over-engineered. With furniture a delicate balance needs to be maintained between strength and weight. The denser the material is the stronger the structure needs to be and this has to be incorporated into the design, and in the process the grace and elegance are lost.

The final research question about whether the plantation timbers can be steam-bent, the answer is: a clear yes, even considering that the timber has been kiln-dried. This was one of the most challenging research questions. The heating involved in the drying and steam reconditioning process changes the structure of the timber making it more difficult to bend³⁸.

With experimentation I was able to modify existing methods of steam-bending enabling significant bends to be achieved. The use of kiln dried material has a major benefit over the bending of green or air dried reconditioned material used by Thonet as the bent sections can be used in furniture manufacture within hours of bending. Green timbers require weeks or months of stabilization after steam bending, before they can be used. The use of plastic bags in the steam-bending process has enabled significant gains to be made in this field.

The twisted lights highlight the advancements that have been made, considering this type of bend is the most difficult to achieve.

³⁸ There is a limited number of times that a piece of timber can be heated before it becomes brittle and unable to be bent

The processing characteristics of the plantation timbers is a key point covered in this research. There have been many questions raised relating to the suitability of the plantation stock for high-grade processing. These questions of suitability have led to a resistance to cutting and downstream processing of the timber.

The extensive investigation into the general properties done as part of this research project has revealed that the workability of these timbers is comparable if not better than that of the currently available native forest eucalypt timber.

The main differences are in the density of the materials covered on page 41. The younger 22.5 year old material has positive aspects for furniture manufacture: the lower density allows for easier working properties with hand and mechanical tools; and these softer materials are an advantage in producing items of furniture as they are lighter and easier to work. To put this in context, the working properties of the *E. nitens* closely resembles that of Blackwood.

The workability of the plantation timbers in processes such as gluing, machining, sanding and finishing tests carried out within this research project demonstrated that there were no outstanding problems.

A noteworthy observation was that the bonding capabilities of the plantation timbers outperformed the control species.

Overall Conclusions: Findings by species

Overall the materials studied within this project were in many respects better than expected. Appropriate primary processing of the materials by the sawmill, through the milling drying and reconditioning stages resulted in few of the defects that have plagued previous trials. This, in part, is due to the older, larger diameter logs produced from the trial sawlog plantations. These larger diameter logs enabled quarter-sawing to be used giving boards well-suited to furniture manufacture. The drying and reconditioning of the timbers also demonstrated far fewer occurrences of pipes, checks and collapse noted in many previous research projects. Overall the plantation timber studied in this project performed as well if not better in furniture-making than the control.

E. obliqua

The selection of the *E. obliqua* as the control was appropriate as it represented the most readily available native-forest eucalypt timber. The supply from the same mill (Britton Timbers Smithton) as the two plantation species made for better comparisons to be drawn between the species as it was processed within the same facility.

There were a number of results with this species that were not expected within the comparative phase of the testing:

- The slight mis-adhesion within one of the glue samples using PVA due to the higher density of the annual rings not allowing full penetration of the adhesive into the surface
- The opening up of micro-checks in the surface of the material when the 38 mm boards were re-sawn then steam bent highlighting the existence of these micro checks within the board

Neither of these were serious enough to prevent the timber's use in furniture-making but were worth noting.

E. globulus

The plantation *E. globulus* from the initial samples was very different from native-forest old growth timber of the same species. These differences were positive as the old growth timber is universally disliked as a timber for furniture-making as it is hard and difficult to cut and glue. This is due to the high concentrations of tannin and waxes that cause saws to overheat and bind as well as cause poor adhesion when gluing. The plantation-grown timber did not demonstrate any of these traits. The plantation-grown material appears to have reached an age where it has stabilised but has not taken on the detrimental traits normally associated with the old growth material.

As a furniture timber the 22.5 year old *E. globulus* shows great potential as the density is higher than the *E. nitens* but is still more user friendly than the *E. obliqua*. The gluing capabilities of the plantation *E. globulus* was impressive considering this has always been identified as a problem with this particular species. The timber's ability to be manipulated by steaming was also far better than expected and in many aspects it can be compared to European Beech (*Fagus sylvatica*) as it is of a similar density, strength and appearance.

E. nitens

Of the two plantation-grown species being studied this initially demonstrated the least promise for integration into high end furniture manufacture. This was due to the samples that were available at the time.

These were from early trials using juvenile trees (15 year old) and milling and drying techniques that were experimental. Previous to this was the commercial trial of Eco-Ash that from unpruned plantation *E. nitens*, this from personal experience was not viable as a timber for high-grade furniture production.

The latter trial conducted by Britton brothers, in Smithton (Pearn et al. 2013) involved logs of 22.5 years of age and a combination of improved growing, milling and drying techniques had produced a material containing fewer defects such as knots and checks.

The improvement from this trial has lifted the timber quality to a point where there is no barrier to its integration into general use in secondary manufacture. The testing done within this project has proved that there are no major issues associated with the use of the *E. nitens* boards of this quality in any furniture-making process.

Another problem previously identified with plantation-grown *E. nitens* has been its lower density: this affected its suitability for applications such as flooring. For furniture-making, this is much less of an issue and in fact can be an advantage. To draw parallels with existing timbers the average density of *E. nitens* is similar to that of Blackwood (*Acacia melanoxylon*) and King Billy Pine (*Athrotaxis selaginoides*); the main point of difference is that from experience gained through this project the *E. nitens* is more robust in its structure, having greater tensile strength and being less prone to fracture than these other species. The strength of the timber allows smaller sections to be used in high-load furniture components.

The pruning of the plantation *E. nitens* used in this project created clear-wood boards that have demonstrated potential to be used in a varying range of higher value applications.

The excellent gluing capability of the *E. nitens* was also noted as a positive factor in the applied testing of the timber.

The steam-bending of the *E. nitens* also demonstrated its ability to outperform the *E. obliqua* in being able to achieve tighter bends with less breakage.

These findings suggest, then, that with the appropriate silviculture, the plantation *E. globulus* and *E. nitens* can provide a valuable and workable resource for high-end manufacture in the furniture and related timber industries.

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This project could not have proceeded without the assistance of bodies such as CSIRO, Forestry Tasmania and Britton Brothers.

I would also like to acknowledge the important financial support given by the National Centre for Future Forest Industries at the University of Tasmania, enabling this project to cover a wider range of eucalypt species.

Appendices

Language of the furniture maker, A-Z

Many of the terms used in this exegesis require explanation, as many are drawn from the Cabinetmaking field. The majority of the terms are drawn from the English traditional craft terminologies. They are not in general use outside this field but they are the best method of explaining the properties and processes undertaken in this research project. There are many other processing terms used that cross boundaries between silviculture, sawmilling, timber drying, general machining and applied finishes that require explanation.

It has become apparent through this research that the terminology used in the timber industry is almost another language.

As a person brought up in this culture of woodworking the terminology is so integrated into the vernacular, to others it is can be almost incomprehensible. So it is necessary to explain and contextualise this specific form of language.

Abrasives

This term relates to the types of paper or cloth-backed materials used to finish timber prior to coating. The various types of grits contained within these are specific to application, for instance, the majority of abrasives used in this research project have been Zinc Stearate based for superior cutting performance in harder timbers.

Annular Ring

This term is used to describe the change in density between the growth cycles that trees undergo in a typical year (Walton & Stanley 1979, p. 192). The harder summer wood is related to the slower growth rate during summer in comparison to the more rapid winter growth. These variations can be dramatic in some species such as *E. nitens* with a wide range of density between the Summer and Spring or winter wood (Bootle 2010, p. 418).

Atypical Wood (reaction wood)

This term refers to the density variations that can exist within the structure of timber. This can be caused by many factors such as the growing conditions that the tree has experienced such as proximity to other trees causing an imbalance within the tree's structure. This can cause problems within the re-sawing process as the release of these tensions can cause distortion of the dry boards.(Bootle 2010, p. 13)

Back-sawn and Quarter-sawn (plane or flat sawn)

Back-sawing is a method of conversion used mostly in minor species logs to create more dramatic figuring as the annular rings are exposed on the wider surface of the board. This is not a method generally recommended in small logs or in eucalypts as the drying of this configuration is prone to significant distortion and degrade within these materials.



Image 90:

Quarter-sawing is the preferred method of cutting eucalypt logs as it decreases the degrading of the timber during drying as the annular ring is across the shortest section of the board.

Bird's eye figuring

This form of condensed knots is usually applied to burls that occur in some minor species. This figure has also been recorded in some plantation logs. Image 91 shows an *E. nitens* log with a large number of bird's eye knots which run through the entire log.



Image 91: (Pearn et al 2013)

The usual reason for this form of tight knot pattern is associated with damage of some form to the growing tree. The heavy concentration in some instances is caused by localized injury where the tree sends out large numbers of small branches and then encases them.

Bleeding

This is usually associated with the seeping of colour either by staining or sap discolouration.

Brittle Heart or Carroty

This defect is either from incorrect drying or from rot being present in the tree (Bootle 2010, p. 27). This is a difficult defect to detect without experience as the markers are very subtle; but to a trained eye they are obvious. The usual markers are slight graduation of colour from core to outer surface on the end section of the board. This colouration goes from dark in the centre of the board to lighter in the outer shell; this is in

reverse of what one might expect to see. The other main marker is the weight of the board: they tend to be unusually heavy for their colour.

Case Hardening

This is a term used to describe the cellular collapse in the outer part of a board associated with defective drying. The collapse of the outer skin of the board does not allow correct transference of moisture and tannins out of the board through the drying process. This can cause darker discolouration in the inner part of the board and also indicates the centre of the board will be reactive when cut.

Catalyst

In woodworking this refers to an accelerant used in either a glue or finish. These are generally oxidising agents used to accelerate the drying of the particular compound. These agents can be reactive to tannins and can be problematic with high tannin species such as Blackwood and Tasmanian oak. The higher the tannin levels are the greater the problem. Specific species such as *E globulus* are prone to reaction with catalysts.

Cellular collapse

This form of collapse can be problematic in species such as *E. nitens* where the structure of the timber is more open containing larger vessels that, as they dry, are prone to collapse. This collapse can cause internal cracking and piping within the board. This has been a particular concern in *E. nitens* during the drying process although, as research into the drying of these species has proved, it can be reduced with the correct drying procedure (Pearn et al. 2013).

Checking or Surface Shakes

This term relates to the surface cracking due to improper drying. The outer surface of the timber is dried too fast causing an imbalance in the shrinkage of the timber. This simply means that the outer surface is dried too rapidly and is usually caused by exposure to direct sunlight (Lloyd & Cowmeadow 1967, p. 55).

Cross Grain scratching

This refers to the scratching that becomes visible when a finish is applied.

Equilibrium Moisture Content

This is the stable level the timber sits at in a given environment for example the general Equilibrium Moisture Content of most timbers in a non-air-conditioned home is 12-14% moisture content.

Fibre

This is a term that is related to a vessel of the timber structure as timber is a material that contains linked cellulose (Walton 1979, p. 198).

Fiddleback figure

This refers to the tight wavy grain structure that is only visible on the quarter-sawn face of the timber. (Bootle 2010, p. 228)

Heart wood

This term relates to the timber towards the centre of the log that has undergone some structural changes. The heart wood of the log tends to be more stable and less reactive than the sapwood or outer part of the log.

The colour is richer in the heart wood section of the log, making it more prized as a furniture timber. The very centre of the log is usually rejected in the milling process particularly in eucalypts.

Hollow planing

This refers to the planing of a curve in the surface of a joint to cope with the expansion and contraction of the timber. If this is not done on widening joints the movement of the timber can cause the joint to fail. The degree that the hollow should represent is approximately .5mm per 500mm. This keeps the solid joint under constant pressure.

Knots – live / embedded or sound knot, dead knot

This form of knot has encased bark surrounding it. If the knot is loose it is classed as dead and if it is fully connected it is classed as sound or live. These are present in the pruned trees as the branches have been trimmed off at an early stage of growth. There is also some indication that the live or embedded knots can lead to figuring similar to large Bird's Eye.

Internal or Growth Stress

The inbuilt stresses contained within a piece of timber can be a significant problem as they are released during the re-sawing process (Lloyd & Cowmeadow 1967, p. 55). This release of the inbuilt stress can cause timber to distort during the last stage of manufacture.

Live Sawing

This is a method of sawing mostly used in softwoods. The method yields greater volumes of sawn timber compared to Quarter or Back-sawing. This method of conversion of logs has proved to be problematic in small

diameter eucalypt logs as the timber produced tends to degrade badly during drying.

Medullary Ray

This term refers to the cell structures that runs radially from the cambial layer to the core of the tree. This forms a light figure particularly in quarter sawn boards as the face of the board exposes the cross section of the cell structure.

Moisture Content

The moisture content of timber is an important aspect of working with timber as this is the relation that the material has with the surrounding environment. The wetter the surrounding atmosphere the more moisture the timber holds and the more it expands. As the atmospheric humidity changes so does the level of moisture that the timber holds. This is a significant variable as the workshop at the College of the Arts runs at less than 10% relative humidity whereas 64% relative humidity is normal in Tasmania. This equates to a moisture content in timber in the workshop registering at under 6% in comparison to the normal household 12-14%. This has to be taken into account when fitting drawers or other components that have to work with tight tolerances.

Orbit marks

This is the scratch mark left in the surface of the timber after sanding with an orbital sanding machine. The marks from this process if not addressed detract from the overall quality result.

Oxidising Dryers

This term relates to the accelerants used in oil finishes. These vary from Polyurethane to Terebine: each is used to speed up the drying of particular oil based finishes.

Piping of cup shake

This form of internal collapse, also known as internal checking, is common within most eucalypt species. This is usually caused during the drying process by severe contraction of the cell



Image 92:

structure. It can be controlled by changes in the drying schedules, and checks can be partly or completely closed during steam reconditioning, although they remain as hairline cracks within the board (Blakemore et al. 2010). The cup shake is usually within the spring wood as this is the softest and most open grained section that in green holds the highest moisture content. As the board is dried this section of the material undergoes the greatest contraction forming the voids. The cup shakes can also continue through the Summer wood section but this is as result of spread from its starting point in the Spring wood section.

Pith

This refers to the very core of the tree, this section of the tree tends to be one of the most unstable sections of the log. This is mostly due to the trace of the original apical meristem, the wider annular ring configuration, and the prevalence of enclosed knots.

Planing

This is the action of using a hand plane or the use of a surface dressing machine (buzzer jointer).

Pore

This term relates to the open vessel structure of timber, vessels being the water-conducting elements of the xylem tissue (Walton 1979, p. 198). This open structural element of the timber can be denoted by a small open pipe or tube-like mark in the surface of timber.

Ragging

This is a term that relates to several effects in engineering and the furniture industry. It refers to the fibres of the material being dragged free of the surface. The result is the tearing of the surface similar to the surface of well-worn fabric.

Re-sawing

This refers to the re-cutting of timber that has been milled and dried in primary processing. This is usually done by either circular saw or bandsaw depending on the setup of the workshop being used. There are a number of considerations taken into account when re-sawing timber, including thickness of the material, species and original milling configuration. These all play an important part in selection of the re-sawing method and particular blade configuration. The blades used in this operation are designed for ripping, they have fewer TPI³⁹ as this allows for a greater amount of material to be removed without choking.

³⁹ TPI, refers to teeth per-inch as this is the standard measure of spacing between the top points of the teeth.

Ribbon Grain or Interlocked Grain

This refers to the common reversal of grain that some timber species display. It is a pattern of fibre direction that causes the material to tear when being planed or dressed.

Sap wood

This is the outer section of the tree that has not stabilized into heart wood. Sapwood tends to be reactive (it moves when being cut), causing subsequent loss of dimension when straightening the material. The sapwood also tends to cause problems when mechanically sanded. It is unclear what causes this issue, but as the sapwood is problematic it is usually removed in the dressing process.

Secret mitre dovetails

These joints have been used where the strength of a dovetail is required but where the cleaner lines of a mitre are preferable. This form of joint is seldom used but when required it forms an effective strong interlocked joint with excellent sheer capabilities.

Shakes

These are cracks in the surface of boards usually caused by exposure to intense drying such as being left uncovered in direct sunlight. This form of degrade usually only occurs in the outer boards of a pack of timber. The cracks are usually superficial, only penetrating 1-3mm into the surface of the board.

Spike or Splay knot

This is common in pruned material as the tree is actively growing over the damaged point. The spike knot occurs in plantation trees that have been pruned as the entrapped branch is absorbed, this can cause a form of figuring where the tree continues to grow over the disturbed section. This type of defect can become an interesting addition to the grain pattern in bland timbers.

Spring wood and Summer wood

Spring wood refers to wider lighter coloured layer of fibre that is softer than the surrounding structure of the timber. This is the wider section of the growth ring as the tree has grown faster during this part of the year. Summer wood refers to the harder darker section of the growth ring. This is caused by the tree's slower growth rate during the dryer part of the year.

Stains

This refers to the natural or artificial colouration applied to timber. This can be done to enhance the features of particular species that can tend to be pale and lifeless without the addition of this pigment. This is a classic technique that has been used since the middle ages to give warmth and depth to timber. The modern stains are either oil or spirit based, depending on the end application. The older forms of staining were water based, these were harder to use but have proved to be longer lasting.

Radial and Tangential expansion and contraction

Refers to the differing rates that timber moves in relation to the direction of the annular rings (radial) and at right angles to the annual rings (tangential) in the boards (Walton 1979, p. 218)

Tannin Discolouration

This is the discolouration caused by an oxidising agent (Bootle 2010, p. 165).

Tacit knowledge (craft knowledge)

This refers to the form of knowledge handed from one generation of craftsmen to the next. This has in the past been through the apprentice training under the tutelage of master of the particular craft. Classically this form of knowledge is not recorded for a number of reasons:

1. The difficulty of describing the subtleties involved within a highly specific form of craft is almost impossible to convey in text form.
2. The ability of the reader to comprehend the notions portrayed as these concepts relies on an experiential learning base that not all possess. One has to have experienced the described to understand it fully.

Crafts such as steam-bending have within history fallen within the Guild system forming a commodity that had value and had to be protected.

Trennel

This refers to a wooden dowel usually tapered on one end and wedged on the other. These have been used in boat building for thousands of years first noted in the burial barge of Pharaoh Khufu 2500 BC. Later used by the Vikings in such vessels as the Oseberg ship 850 AD.

Widening Joint

Widening joint refers to the edge jointing of boards to form larger panels or table tops. The process involves the planing and fitting of the meeting surfaces, with a slight hollow planed in the centre of the board. This is done to ensure that the top is jointed under pressure, the allowance of this concavity is dependent on the timber species. The rule of thumb is 0.5 mm per 500 mm although this can change dependent on the resistance of the material. The purpose is to ensure that the joint is always under tension, because as the timber moves the joint is always under compressive force. This equates to the joint being under either more or less pressure keeping the ends of the joint from failing.

Working of Wood

Expansion and contraction of timber due to changes in the atmospheric relative humidity levels. This variation continues as a constant expansion and contraction process for the life of the piece of timber. The usual expansion and contraction rate for the species covered in this project is .7 mm per 100 mm summer to winter. This is the rate that the material moves in relation to environmental changes. For example a 1000mm wide jointed table top created out of solid timber may grow in width by up to 7mm if the relative humidity increases dramatically.

Annotated bibliography

1. Ashley, P, Gordon, N, Stanley, B, & Wilbrink, F, Computer Numerical Control (CNC) 2006. The future of eucalypts for wood products, Proceedings of IUFRO conference 19-24 March, 2000, Launceston, Tasmania, Australia, pp. 150-158. This article discusses the use of CNC machinery and how the approach is different in an Australian context. The identification of items such as snap together shelving made from ply was also of interest as this relates to the production of ply from *E. nitens*. This was done to link the work carried out on a design of a set of book shelves that was not submitted as part of this project due to un-availability of the plantation plywood.

<http://issinstitute.org.au/wp-content/media/2011/05/ISS-FEL-REPORT-ASHLEY-GORDON-STANLEY-WILBRINK-lo-res.pdf>

2. Ashley, P, & Ozarska, B, 2000. Furniture from young plantation grown eucalypts, The Future of Eucalypts for Wood Production, pp. 150-158. Innovative and Interdisciplinary use of Computer Numerical Control (CNC) Manufacturing Solutions for the Design and Manufacture of Furniture and Building Products using Limited Resources in a Targeted and Effective Manner, ISS Institute Report, Victoria

As this is early in the chain of research this was of interest because it identified the work needed to bring the plantation stock up to a stage that it could be integrated into production. This conference paper delivered in Launceston was at the beginning of the discussions about using a resource primarily developed to supply the fibre market, and contemplate other higher value options for the material.

<https://publications.csiro.au/rpr/pub?list=BRO&pid=procite:a02e3900-3e58-427d-b0d6-847805added6>

3. Beadle, C, Volker, P, Bird, T, Mohammed, C, Barry, K, Pinkard, L, Wiseman, D, Harwood, C, Washusen, R, & Wardlaw, T, 2008. Solid wood production from temperate eucalypt plantations: a Tasmanian case study, *Southern Forests: a Journal of Forest Science*, vol. 70, no. 1, pp. 45-57.

This review summarises research on several key areas: silvicultural requirements for solid wood production; wood properties of plantation-grown eucalypts and the influence of silviculture and genetics on these properties. They concluded that there were operational challenges to be confronted in the production of solid wood from plantations. These challenges were met in later research however it was necessary to look into this to gain a background on development of processes undertaken on the plantation timbers.

<http://www.parliament.tas.gov.au/ctee/Council/Submissions/Govt%20A%20TransitionOutOfPublicNativeForests%20-%20CRC%20Part%202.pdf>

4. Blakemore, P, Morrow, A, Ngo, D, Washusen, R, Harwood, C, & Northway, R, 2010. Plantation-grown *Eucalyptus E. nitens*: Solid wood quality and processing performance on linear sawing systems with a range of commercial and experimental drying schedules, CRC for Forestry Technical Report, vol. 200.

This report covered the results of milling trials on pruned and thinned *E. nitens* from a plantation in North East Tasmania. The results of this project were processes that reduced the degree of internal degrade and surface checking leading to a higher

percentage of high grade boards. This research is of interest because the higher grade outputs lead to high-end applications that are the focus of this project.

<http://www.crcforestry.com.au/publications/downloads/TR200-harwood.pdf>

5. Bootle, KR, 2010. *Wood in Australia: types, properties and uses*, 2nd edn, McGraw-Hill, Sydney.

This book covers a number of aspects of working with timbers. The mechanical properties and in particular the figures relating to expansion and contraction of Australian timbers. These statistics relate to mature trees but for this project it is important to be able to compare results with existing knowledge. This text is recognised as the standard in woodworking for the general properties of Australian native species.

This book contains the benchmark information on Minor Species and how they relate to international species. From a craft angle these Minor Species, particularly in Tasmania, cover species such as Huon Pine, (*Lagarostrobos franklinii*) Blackwood, (*Acacia melanoxylon*) Sassafras, (*Atherosperma moschatum*) Myrtle, (*Lophostemon Cunninghamii*) and Celery-top pine (*Phyllocladus aspleniifolius*) there are many more but these are the major commercial ones.

The majority of high end craft revolves around this group of species due to the rarity and prized nature of the material. As these species have attracted higher premium prices the use of them has made items made from them more marketable.

The rare and bankable nature of these specialty materials has been a cornerstone of the local fine furniture and wood product market for generations.

This, in some sense, has led to a reliance on the material not the design selling an item. With the change in forest practices (the move away from clear felling of native forest) that has driven the minor species sector for many years. The volumes of this material will not be available in the large quantities as it has been in the past. The reliance on these Minor Species has led to the majority of the craft knowledge concentrating around these species. So it is critical that this project be able to draw comparisons with current benchmarks enabling these plantation materials to become more widely accepted.

This research project explores the possibilities of the plantation eucalypts augmenting a proportion of this high end craft based manufacture, currently centred on the dwindling stocks of Minor species.

6. Cochrane, G, 1992. *The Craft Movement in Australia: A History*, Sydney, UNSW Press.

Grace Cochrane observed that after World War I manufacturing, which had doubled in the thirties further developed during World War II to produce clothing and armaments. This impetus was expended on domestic products in an economy riding on the sheep's back. Migration from Europe brought many families with technical skills and high cultural values. Once they gained their bearings they set about enriching the Australia culture and its economy.

Then in 1972, the Australian Government responded with the formation of the Australia Council and the effects upon the arts and crafts was dramatic, as for the first time the States and Territories were drawn together by a national overview and the finance to stimulate the development of a national identity.

7. De Fégely, R, 2004. Sawing regrowth and plantation hardwoods with particular reference to growth stresses, Report Project no. PN02, vol. 1308.

This report, which comes in two parts, identifies the inbuilt stresses that can cause problems in juvenile eucalypts. These defects can cause serious degrade in the late stages of production. This point of internal stresses is also identified in other reports particularly using younger trees. This is problematic as it causes the log to move and distort causing variations in thickness and width of boards. This report has been used continuously as evidence that there are issues with the plantation species. The problems identified by this report have been addressed by many later reports and research projects, however this report continues to be referred to give credence to contrary points of view. The report was based on very small diameter logs using a milling technique that has been proved not to work, leading to the un-favourable results.

<http://www.fwpa.com.au/images/processing/PN02.1308%20sawing%20regrowth%20part%20A%20WEB.pdf>

8. Dormer, P, 1994. *The Art of the Maker. Skill and its Meaning in Art, Craft and Design* London: Thames & Hudson.

The Art of the Maker also draws together the concepts of craft knowledge and tacit knowledge. The term tacit has been linked to the concept of the “dumb artisan” (tacit, taciturn) (Dormer 1994, p. 15) which can have several meanings. The most relevant would be “Tacit” from the Latin “tacere” to be silent. From the Latin “Taciturn” translates to reserved, uncommunicable. This all fits with this form of knowledge being almost impossible to communicate to the general public. Dormer states “Acquiring a body of knowledge takes time: it is a slow empirical process. Intellectual leaps via theoretical insights are useful, but only after practice” Dormer (1994, p. 56).

The acquiring of knowledge and the pursuit of perfection involves an almost Zen like preparation and execution of process. The almost ritualistic approach that a master of any art or craft goes through forms part of the creative process. This is more than just trained muscle memory. It is far deeper and more liberating than just repeating the same process that one has done hundreds, if not thousands, of times. ‘Visual thinkers’ are also discussed by Dormer (1994, p. 58). The author makes the point that the ability to visualise in 3 dimensions is a talent often possessed by the top echelon of crafts people. Peter Dormer is important to this project as he sets much of the theoretical context of craft knowledge.

9. Dormer, P, 1997. *The culture of craft*, London, Manchester University Press.

This discusses the Bauhaus and its influence on art and architecture of the twentieth century. There are many polarising views and comments in this text relating to the

status of craft and its standing in the arts. These only add to the divide between these fields and are not helpful in a contemporary setting. Some of the influential designs from this period are the Wassily Chair, also known as the Model B3 chair, which was designed by Marcel Breuer in 1925-1926. This simple tubular construction uses the elasticity of the covering materials to create the seating and this immediately changes the chair from a hard architectural form that does not appear to be usable as a seat into one of the most admired furniture forms of the twentieth century.

10. Forestry Tasmania, 2014. Sustainable high quality eucalypt sawlog supply from Tasmania's Permanent Timber Production Zone Land, Forestry Tasmania.

This report was used to gauge the availability of the plantation resource and the projected yields of this timber. This was done to ascertain the potential that these plantation eucalypt species hold into the future. The report identifies the volumes of timber that will be coming on-line. These statistics were invaluable in determining the ongoing viability of this material. The statistics are that there is approximately 105,000 cubic meters of plantation stock per annum. This is a significant resource that this project addresses additional uses for. This volume is predicted to maintain stable supplies through to 2098 and beyond.

http://webarchive.linc.tas.gov.au/20120327023005/http://www.environment.gov.au/land/forests/independent-verification/pubs/ivg_woodsupply_burgman.pdf

11. Gaunt, D, Penellum, B, & McKenzie, HM, 2003. *Eucalyptus nitens* laminated veneer lumber structural properties, New Zealand Journal of Forestry Science, vol. 33, no. 1, pp. 114-125.

This article looks at *E. nitens* as a timber for use in LVL (Laminate Veneer Lumber) for large structural applications. The relevance to this project is the gluing of the material. This was to ascertain if there were any issues relating to the adhesion of this timber noted. There were none identified and in subsequent testing within this project there proved to be positive elements to the gluing properties of the plantation *E. nitens*. The tests carried out on the *E. nitens* within this project identified that the timber glued better than the native forest eucalypt samples.

12. Herrigel, E, 1948. Germany: Baden-Württemberg, *Zen and the Art of Archery*, covers the mental approach that allows the mind to control the overall outcome allowing the body to do what it knows how to do. This concept is also explored in *Position Rifle Shooting* (Pullum & Hanenkrat 1973). This is a concept explored by many other texts relating to the process of hand making and the application of craft knowledge. The concept of the trained crafts-person being able to achieve tasks with apparent ease and levels of perfection that almost defies belief.

13. Joyce, E, 1970. *The technique of furniture making*, London: Batsford,

This book is a refined addition to the information contained within Walton (1947) and Walton (1979). It is not possible to gain the full benefit of this book unless one has first read

Woodwork in Theory and Practice as the basic concepts are expanded in this text.

Joyce & Peters make a number of assumptions and the style of writing tends to expect a level of consolidated knowledge to exist in the reader. The information in this book adds a level of finesse to techniques and processes covered in many other texts: the focus of this text is on high end wood craft. This book expertly explains the long-standing vernacular used to inform the craft of woodworking.

The major relevance of this text to this project relates particularly to the Alan Peters 1987 revised addition, as the information contained in this version takes into account major advancements in timber technologies in the early 80s.

14. Kibblewhite, RP, Johnson, BI, & Shelbourne, CJA, 2001. 'Kraft pulp qualities of *Eucalyptus nitens*, *E. globulus*, and *E. maidenii*, at ages 8 and 11 years'. Conference (55th: 2001 : Hobart, Tas.). 55th Appita Annual Conference, Hobart, Australia 30 April-2 May 2001: Proceedings. Carlton, Vic.: Appita Inc., 2001: 14-20.

This paper has a breakdown of the chemical compounds contained within *E. nitens* identifying elevated levels of xylose (sugar) within this species. This in other species such as Sassafras (*Atherosperma moschatum*) causes surface discolouration during drying as the oxidation of the tannins and naturally occurring xylose leave a dark stain deep into the surface of the timber. These dark stains are present in some of the samples tested, there was also a noticable sweet odour when the *E. nitens* was steamed. This is the most likely reason for the staining.

15. Krenov, J, 1976. *A cabinetmaker's notebook*, New York: Van Nostrand Reinhold Co.

James Krenov (1920-2009) is regarded as one of the great makers and authors writing on woodcraft of the twentieth century. His landmark book, *A cabinetmaker's notebook* Krenov (1976) was a great introduction to the North American wood-working culture and was widely seen as a rite of passage into the world of wood for a large number of wood craftsmen and designers.

Although the images and ethos behind Krenov's work may seem conceptually alien to most production furniture makers, conditioned to create work to strict schedules and restricted use of materials, the book introduced readers to an array of timber applications and processes and offered a new perception of what is possible in the world of furniture making. This of all his books spawned many committed craftsmen over the next decades, as the concept of taking a basic knowledge of woodworking and elevating it to an art form generated new and exciting opportunities for makers.

16. Krenov, J, 1977. *The fine art of cabinetmaking*, New York: Van Nostrand Reinhold.

The fine art of cabinetmaking, explores the concept of wood craft as an independent art form where a careful and respectful treatment of timber as a living and breathing immersive medium sets Krenov apart from others in the field at the time. His autobiography explores the backwoods philosophy and lifestyle

of a highly attuned craftsman and is richly illustrated with many examples of his own works.

17. Krenov, J, 1979. *The impractical cabinetmaker*, New York: Van Nostrand Reinhold Co.

Represented in this book are James Krenov's delicate cabinets that have inspired generations of craftsmen, as well as his impassioned insistence that one does one's very best work, no matter what. In this volume, first published in 1979, Krenov invites the reader into his workshop, where he shares his techniques and his philosophy of uncompromising craftsmanship, along with thoughts about his work and its place in the world.

18. Krenov, J, 1981. *James Krenov, worker in wood*, New York: Van Nostrand Reinhold Co.

This autobiographical text deals with the intimate nature of woodworking as an immersive experience. The most poignant quote is: *"To the open, curious eye it will convey not only aspects of personal expression-a quiet sensitivity-but also an intimacy in the way the work has been done. Gentleness of line, clarity of surfaces that have shimmer and lustre, traces of delicate tools used with patients and purpose-those do tell a story."* This sums up the deep connection that woodworkers share with the materials that they work with.

19. Krenov, J, & Janofsky, S, 2000. *With wakened hands*, New York: Cambium Press.

With wakened hands explores the philosophy that underpins his approach to making – and is a mature reflection on his extensive teaching of the preceding decades. Not only does it explore his

own work but also incorporates a large amount of student work, and the book is an excellent example of that tradition of knowledge transfer that dominates the crafts – the notion of the master passing on knowledge to an apprentice by practical example.

20. Lloyd, C, & Cowmeadow, AC, 1966. *Furniture and Cabinet Making*. Melbourne.

This reference manual identifies internal stresses in dry timber on page 55. This phenomenon is hinted at in many other technical manuals but is identified specifically in this text. These forms of internal stresses are relevant to the re-sawing of dry timber as they can cause significant loose of dimension due to warping. The growth stress in juvenile eucalypts has been identified in scientific studies such as De Fégely (2004), Vázquez (2001), Wardrop (1956), Washusen, (2011,b) these identified the issue in the milling of green logs. These stresses are still present in the dry timbers as identified in this reference text. This releasing of inbuilt tension is an expected consequence of the re-sawing process that forms part of the handing down of knowledge rather than the documenting in texts. This is also a point that has not been captured in scientific data. Within the furniture field it is widely accepted that in-built stresses are still present in some boards. It was necessary within this project to capture this point as this links in with the existing chain of research. Particularly the identified movement issues in the preliminary processing of the plantation eucalypts Nutto & Becker (2009), De Fégely (2004), Valencia et al. (2011)

21. McGavin, RL, Bailleres, H, Lane, F, Blackburn, D, Vega, M, & Ozarska, B, 2013. Veneer recovery analysis of plantation

eucalypt species using spindleless lathe technology, BioResources, vol. 9, no. 1, pp. 613-627.

This report delves into the production of rotary peeled veneers using *E. nitens* and using spindleless lathes. This is of interest as the production of ply from the plantation species opens up opportunities for expanded integration of the *E. nitens* into other applications. This aspect was explored to incorporate into the submission however there was no extended supply of the material available. There was a set of shelves produced for an exhibition (InForm) and proved the concept viable.

22. Nolan, G, Greaves, B, Washusen, R, Parsons, M, & Jennings, S 2005. Eucalypt Plantations for Solid Wood Products in Australia-A Review 'If you don't prune it, we can't use it'.

This major government review published in 2005, carried out by the Forest & Wood Products Research and Development Corporation is a comprehensive report on the status of the plantation hardwood resource and explores the factors affecting its future sustainability in very considerable detail. Published a decade ago by authors Nolan, Washusen, Jennings, Greaves and Parsons, the review retains its importance because of the emphasis it places on the application of appropriate silviculture techniques throughout the life cycle of Australian hardwoods until they are selected for harvesting.

The authors demonstrate how essential it is to ensure that pruning of plantation trees occurs during the early stages of growth. This produces a far higher quality of product, important for sawn logs for the high end timber and furniture industries, since failing to prune early leads to significant defects in the timber once sawn. If limbs are left on the tree, the knots that occur in the sawn product form structural defects that can

downgrade the timber and render it unusable for higher end applications. It is also important to note that the emphasis on early and regular pruning leads to a further significant benefit in that as the trees make their recovery from pruning, it produces figuring that is prized in furniture for its decorative qualities.

http://eprints.utas.edu.au/7045/1/FWP-8_PN04.3002.pdf

23. Ozarska, B, 1999. A review of the utilisation of hardwoods for LVL, Wood Science and Technology, vol. 33, no. 4, pp. 341-351.

This report was interesting as the North American species discussed in this have a density of 390 to 500 kg/m³. This is a similar range to *E. nitens* opening up other possible uses for this timber. One of the criticisms of the *E. nitens* is its lack of density compared to standard eucalypt species such as *E. obliqua* with an average density of 780 kg/m³. This report goes hand in hand with the later LVL (Laminated Veneered Lumber) trials from New Zealand Gaunt, Penellum & McKenzie (2003). The diversification of the plantation timbers into other products is an avenue that needs to be explored to add to the context for this project. The application of plantation eucalypt into LVL as well as CLT (Cross Laminated Timber) open the options for a wider range of possible uses for the plantation materials. The technology used in these processes also has implications for the furniture industry.

24. Pearn, G, Britton, S, Wood, M, Lee, M, Adams, P, Dion, M, & Leigh, E, 2013. Sawing and drying plantation grown *E. nitens* and *E. globulus*, Forestry Tasmania, Tasmania.

This is a pivotal report as it relates directly to the materials used in this project. This is a commercial trial undertaken using

standard production methods such as quarter-sawing Bootle (2010), Walton (1947).

This method of re-sawing logs is standard in all eucalypt processing and although it may not return the volume recovery of other methods it reduces degrade during drying. This trial used previous research on drying plantation eucalypt Blakemore et al. (2010) thus improving the quality of the resulting timber.

This trial was able to produce larger section material with minimal internal collapse increasing its overall quality. The trial used existing equipment and techniques proving that the plantation materials are commercial viable without the need to invest in specialized plant and equipment.

25. Rozas, C, Schimleck, L, & Blakemore, P, 2000. Use of wood from *Eucalyptus globulus* and *E. nitens* plantations for the furniture industry, in Proceedings of 26th Forest Products Research Conference: Research developments and industrial applications and Wood Waste Forum, Clayton, Victoria, Australia, 19-21 June 2000, pp. 25-26.

This conference paper discussed the possibilities for *E. nitens* use in furniture. The material that they were reporting on was only 15 years of age and suffered from major cellular collapse. This collapse and distortion was mostly due to the small diameter logs used for the project. The small diameter logs necessitating a milling strategy yielding mostly back-sawn boards. These in any eucalypt cause drying defects to be amplified. This was one of the first of the research projects specifically looking at high end applications of *E. nitens* but as

the drying had not been perfected at the time the end results were inconclusive. Later reports such as Washusen, (2011,b), Washusen et al. (2009) moved forward from this starting point. The small initial volumes of these early trials made it difficult to draw substantive findings on its suitability for high-end products. The particular relevance to this project is to give a background to this current project and lay out the preceding chain of research.

<http://www.cabdirect.org/abstracts/20023074810.html;jsessionid=0A29DDD1EA4201C184B80204E96BDE94>

26. Sennett, R, 2008. *The craftsman*, New Haven, New York: Yale University Press.

This book has been influential in developing an understanding of such concepts as tacit knowledge and the training of the crafts-person, and especially of the time-based requirements of the acquisition of craft knowledge. He writes extensively about the idea that it takes around 10,000 hours of practice to reach a level of expertise to perform at the highest of levels. The idea was first popularised in Malcolm Gladwell's book *Outliers: The Story of Success*, Gladwell (2008) in which he repeatedly referred to the 10,000 hour 'rule' but there has also been a quite significant amount of research into the requirements needed to achieve the practical expertise in high-performance disciplines. A noteworthy example has been the article written by K A Ericsson, R T Krampe and C Tesch-Römer (1993) titled The role of Deliberate Practice in the Acquisition of Expert Performance, Ericsson et al (1993, pp. Vol 100,363-406) in which the authors provide a sophisticated analysis of the length of time it takes to reach an elite level of musical performance, taking the example of a group of outstanding violinists in a

Berlin conservatorium who were compared to a matched group of good violinists from the same institution and another matched group of music education students studying the violin.

27. Studhalter, B, Ozarska, B, & Siemon, G, 2009. Temperature and moisture content behaviour in microwave heated wood prior to bending–Mountain Ash (*Eucalyptus regnans*), European Journal of Wood and Wood Products, vol. 67, no. 2, pp. 237-239.

This was of interest as to other possible methods of bending timber, however it proved to be too expensive to consider as a possible avenue to pursue. The comparative bends achieved in this research match the ones laid out in Bootle and these have been proved achievable by conventional methods. There were other considerations in not pursuing this methodology as it is done on semi-green material and experience has shown that this tends to leave in a large proportion of tannin causing many other issues in later processes. This was also the case with Thonet and their bent wood chairs, the bending in semi green timber locked in tannin and is still a problem in sanding or cutting any part of these chairs. It is incredible that a process done to a piece of wood in some cases over a hundred years ago still causes a problem when worked on today.

<http://link.springer.com/article/10.1007/s00107-008-0300-2#/page-1>

28. Tibbits, W, 1986. Eucalypt plantations in Tasmania, Australian Forestry, vol. 49, no. 4, pp. 219-225.

This report documented the ramping up of plantation *E. globulus* and *E. nitens* from the start of the 1970s with planting rates at that time of 20 hectares per year. Today the Tasmanian

Permanent Timber Production Zone stands at 800,000 hectares of Land, Forestry Tasmania (2014, p. 19). This significant shift in the management of the forest holdings has enabled the expected yield of 137,000 cubic meters of high grade sawlog per year Forestry Tasmania (2014, p. 19 figure 8). This is important to note in this project as it gives an indication as to possible volumes of material available for use. It is important to note that the ramping up of these plantations has been to offset the declining use of native forest timbers.

29. Walton, JA, & Stanley, L, 1979. *Woodwork in theory and practice*, Sydney: Australasian Publishing Company.

This text represents the basic text that woodworkers generally use as first step into the craft. This represents the equivalent of a collection of school texts dating back to 1937 and is commonly referred to as the “Woodworkers Bible” as this represents the first step into the field for many woodworkers. The book is a collection of many articles from previous books and journals. This has been the standard High school text since its first publication and on reflection represents the equivalent to a cooking almanac. These are the steps to achieve a desired result, and there are few woodworkers that would not have a copy of this book on their shelves. The relevance to this project lies in the background information held in this text that gives credence to comparative processes. These processes are ones that have been built up over generations of woodworkers forming part of the collective knowledge of the craft.

30. Washusen, R, 2011. Processing plantation grown *Eucalyptus globulus* and *Eucalyptus nitens* for solid wood products – is it viable?. p. 30. Technical Report 209, Tasmania, CRC Forestry.

This article highlight the need to treat these plantation timbers in a much more scientific way when drying and reconditioning. The old growth timbers that saw millers are familiar with are much more forgiving when being processed. This report identifies that if the plantation timbers are carefully treated they can produce viable quality material. This primary processing is critical to the end user as drying defects can cause major issues causing the timber to be unusable for high-end manufacture.

31. Washusen, R, 2013. Processing methods for production of solid wood products from plantation-grown Eucalyptus species of importance to Australia, Forest & Wood Products Australia Limited, no. Project No: PNB291-1112A, p. 55.

This report is the latest in the string of reports on the primary processing of the plantation eucalypts, this represents the most accurate over view of the research to date. This is of relevance to this research project as it identifies the issues that have been plaguing this primary processing of these plantation eucalypts, and identifies the solutions to the majority of the problems associated with the primary processing

32. Washusen, R, Harwood, C, Morrow, A, Northway, R, Valencia, J, Volker, P, Wood, M, & Farrell, R, 2009. Pruned plantation grown *Eucalyptus nitens*: effect of thinning and conventional processing practices on sawn board quality and recovery, New Zealand Journal of Forestry Science, vol. 39, pp. 39-55.

This article from the New Zealand Journal of Forestry Science discussed the thinning and pruning of plantations and how it improves the end product as the trees are allowed to grow in a more controlled manner and not competing with other stems.

The pruning of the stands links in with Nolan et al. (2005) allowing for greater percentage of clear wood to be produced.

<http://www.cabdirect.org/abstracts/20103084320.html>

33. Washusen, R, Morrow, A, Valencia, JC, Volker, P, Wood, M, Harwood, C, Innes, T, Ngo, D, & Northway, R, 2007. Gould's Country *Eucalyptus nitens* thinning trial: solid wood quality and processing performance using conventional processing strategies, Technical Report 168, Hobart, Cooperative Research Centre for Forestry.

This report covers the processing of 21 year old *E. nitens* logs that had been pruned and thinned to determine the recovery of sawn boards. Using conventional milling processes and grading (AS 2796.1)⁴⁰ to assess the economic viability of the *E. nitens* as a sawn board product. The points of relevance to this project are in the identification of the problems associated with the sawing strategy. The back-sawing of this material is not an option for high-end applications as there are too many risks of continuing movement issues. The long term stability of boards becomes an issue for end users as they keep moving for the life of the material, this can cause the boards to fail potentially years after a piece of furniture is completed.

<http://www.crcforestry.com.au/publications/downloads/TR168-Washusen-et-al-FORPRINT.pdf>

34. Washusen, R, Reeves, K, Hingston, R, Davis, S, Menz, D, & Morrow, A, 2004. Processing pruned and unpruned *Eucalyptus*

⁴⁰ This Standard was prepared by Joint Standards Australian/Standards New Zealand Committee TM/7, Sawn, Milled and Specialty Timber Products, to supersede (in part) AS 2796—1985, Timber—Seasoned hardwood—Milled products, (in part) AS 1261—1972, Wood mosaic parquet, AS 2796.P1—1985, Wall chart—Summary of surface finishes for seasoned hardwood milled products (in accordance with AS 2796),

globulus managed for sawlog production to produce high value products, PN03, vol. 1315.

This report centred on a wide spread of ages in thinned and unthinned *E. globulus* from Tumit in Victoria. The comparisons between the thinned and pruned plantations were done specifically to determine the suitability of these products for high value added processing. The recommendations from this report identify that if plantation trees are thinned and pruned at 3-5 years of age the logs produced greater returns of high quality timber. The relevance for this research is that if the trees are managed in this way, produce timber that can be used for applications such as the ones done as part of this project.

<http://www.fwpa.com.au/images/processing/PN03.1315.pdf>

35. West, TG, 1991. *In the mind's eye: Visual thinkers, gifted people with learning difficulties, computer images, and the ironies of creativity*, New York, Prometheus Books.

This text was of interest as it filled in many gaps in describing one contributing factor to taciturn, as many high achieving practical people have difficulty in documenting their practice. The inability to read, write and spell tend to direct people into practical endeavours rather than academic pursuits. This is the case with some forms of dyslexia and this book identifies that people who are visual thinkers tend to be innovative and think outside the normal boundaries. The relevance to this project is the author of this research project has struggled with a form of dyslexia all his life and the book offers a reassuring view of the importance of visual thinkers who work in a different language, so to speak, and provide a different form of communication.

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